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The axial fatigue resistance in air and sea water of single wires, strand and wire rope measured in a laboratory experiment is reported. A high frequency Amsler Vibrophore was applied with an identical load spectrum to all three types of specimen. The effect of construction and core on the fatigue resistance of four different wire ropes also was examined. No predictive relationship was found among wire, strand and wire rope. An ANOVA, performed on the air and sea water data of wire rope, helped identify the effect of test variables. Load range, construction, and core had the greatest effect on fatigue resistance. Of the four types of rope examined, ~~Lang,~~ IWRC is recommended for marine applications.

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III

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AXIAL FATIGUE OF
WIRE ROPE IN SEA WATER

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Final Report
Contract N 00024-71-C-5471

June 15, 1972

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Authorization

This study was performed under U. S. Navy Contract No. N00024-71-C-5471 and monitored by Mr. John Wynn, NAVSEC 6162D. The experiments were performed in the Fatigue Testing Laboratory, Civil and Mechanical Engineering Department, The Catholic University of America, Washington, D. C. 20017.

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ABSTRACT

Fatigue failure of wire rope is a major problem for users in industry and government. In marine applications of wire rope, fatigue failure is accelerated by the corrosive attack of sea water.

The axial fatigue resistance in air and sea water of single wires, strand and wire rope measured in a laboratory experiment is reported. A high frequency Amsler Vibrophore was applied with an identical load spectrum to all three types of specimen. The effect of construction and core on the fatigue resistance of four different wire ropes also was examined. No predictive relationship was found among wire, strand and wire rope. An ANOVA, performed on the air and sea water data of wire rope, helped identify the effect of test variables. Load range, construction, and core had the greatest effect on fatigue resistance. Of the four types of rope examined, Lang, IWRC is recommended for marine applications.

NOMENCLATURE

1. For detailed description of terms related to wire, strand and wire rope, see Appendix A.

2. Construction: refers to either Lang or Regular construction of wire rope. In Lang, the wrap direction of wire and strand are the same; in Regular, they are opposite.

3. Core: the center of a wire rope which supports the strands.

4. Breaking Load (BL): the number of pounds required to break specimen in tension.

5. Mean Load: the constant tensile load applied to the specimen expressed as a per cent of the breaking load.

6. Load Range: the fluctuating tensile load applied to the specimen expressed as a per cent of the breaking load. It is the difference between the minimum and maximum load. In this study, the load oscillated equally about the constant Mean Load.

7. Fatigue Life: number of cycles of fluctuating load endured before failure.

8. Lubricant: an asphalt or grease based compound applied to wires and strands when they are closed to make respectively strand and wire rope.

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CHAPTER I

INTRODUCTION

The operation of the deep sea moor, TOTO II, was terminated after four and one half years service in November, 1966. The moor's premature failure was caused by axial corrosion fatigue of two $1\frac{1}{4}$-inch diameter wire rope risers (1, 2).

Examination of a wire rope which fails in service frequently reveals the cause to be fatigue failure of individual wires and strands. Although arbitrary, the definition of a wire rope fatigue failure is generally stated as the number of broken wires per linear measurement of rope. Such a failure results from cyclic loading below the breaking load. The repetitive load application can result from strumming, dancing, shock loads, bending over sheaves, and axial loading. Five different modes of bending fatigue failure in rope wires have been identified by Gibson (3). The orientation of the fracture surface, either normal or inclined to the wire axis, separates two types of failure. The fatigue crack initiation site defines all five failure modes. A recent survey by Chase (4) disclosed that twenty per cent of all wire rope failures in oceanographic work are attributed to fatigue. Respondents in this survey included both users and manufacturers of wire

rope. They identified unsuitable construction as being the cause of twenty-eight per cent of wire rope failures. Fatigue failure of wire ropes was cited by Stimson (5) as one of three primary causes of deep-sea mooring losses and buoy system failures. The response of attendees at a recent conference on wire rope also accented the importance of wire rope fatigue (6).

Fatigue failure of wire rope is a major problem for users in industry and government. There is a lack of sufficient empirical information for the design or selection of wire ropes. Wilson (7) blames the lack of wire rope fatigue data for requiring designers to estimate wire rope fatigue life on the basis of solid specimen tests. The paucity of information on the dynamic endurance of wire rope makes the selection of the correct wire rope a difficult task (8). Work has been performed in the reversed bending mode by Gambrell (9) for the special case of arrest cables on aircraft carriers. Brief studies have been conducted to evaluate the effect of surface coatings or core material on the fatigue life of wire ropes (10, 11, 12). Data buoy mooring cables have received special attention from one of the world's principal users, Woods Hole Oceanographic Institute (13).

There also is a lack of theoretical models for predicting the fatigue failure of wire rope. Only a single prediction model by Drucker and Tachau (14) has wide use. It, however, is limited to the bending-over-sheaves loading mode. A preliminary

attempt by Allen (15) to predict fatigue failure under axial loading of a single strand contains many admitted restrictions. These must be eliminated before the model can be useful. The lack of empirical fatigue data for strands makes it impossible to verify this model.

In marine applications of wire rope, fatigue failure frequently is accelerated by the corrosive attack of sea water. Galvanic corrosion of metals, its control, and prevention is covered by Uhlig (16) and Champion (17). Certain aspects of the corrosion process must be understood to appreciate the type of corrosion attack undergone by wire rope in the ocean environment. A metal surface in contact with an electrolytic solution such as sea water becomes part of an electric circuit. At various surface locations, the metal atoms lose electrons and become anions in accordance with the electrochemical equation, $M = M^+ + e^-$. At the anode location, the soluble metal anions enter the solution and the metal surface is corroded. The free electrons from the anode flow through the metal to another surface location. They chemically combine at the metal surface according to the equation $4e^- + O_2 + 2H_2O = 4OH^-$. Notice that oxygen is required at the cathode location.

Portions of a wire rope surrounded by oxygen-rich sea water, therefore, will behave as the cathode with respect to portions in less oxygenated sea water. The outer parts of a wire rope become cathodic and the bottom of interstrand valleys becomes anodic when the solution in these valleys is stagnant

or when more oxygen can reach the outer surfaces of the wire rope.

The preceding description of the corrosion process explains why the intensity of the corrosive attack varies along the length of a wire rope. It depends on the location of the wire rope within the oxygen profile of the ocean environment. Masubuchi (18) describes the extremely high corrosion rates of 17 mpy (milli-inches per year) found in the splash zone and the low rates of 2 mpy in the tidal zone. Wire rope, reports Wood (19), is susceptible to three types of corrosive attack. Uniform corrosion occurs on individual strands and over short lengths of rope when the entire surface area behaves as an anode with respect to other portions of the wire rope. Crevice corrosion is a localized attack in the valleys between strands or between single wires. Pitting corrosion occurs at isolated points on the surface of individual wires.

The corrosion ~~fatigue failure of wire rope in the~~ ocean environment is the result of a three stage mechanism. Crevice and pitting corrosion initiate the fatigue crack which propagates under the control of the variable stress loading and corrosive attack of the sea water. The cross sectional area of the wire eventually is reduced so that shear fracture completes the failure.

Mehdizadeh, et al. (20) note corrosion fatigue of steel depends on its chemical composition, nature of loading and duration of exposure. The initiation of the corrosion fatigue crack, according to Rollins, et al. (21), is a function of the

corrosion rate of the metal and the sea water's tendency to cause crevice or pitting corrosion. Crooker and Lange (22) found a 3.5% salt water environment caused a higher rate of fatigue crack growth than an air environment. Gilbert (23) offers a complete review of corrosion fatigue, a complex process which is not yet fully understood.

This study measured the axial fatigue resistance of single wires, strands, and wire rope under the same loading spectrum. The grade of improved plow steel, surface coating, and end grips were kept constant while the wire rope construction and core were varied. Tests were conducted in air and in sea water. The information presented here has not been reported previously in the open literature. It should permit users to select the proper wire rope and improve their replacement policy. Manufacturers could use the data presented to improve the design of wire rope.

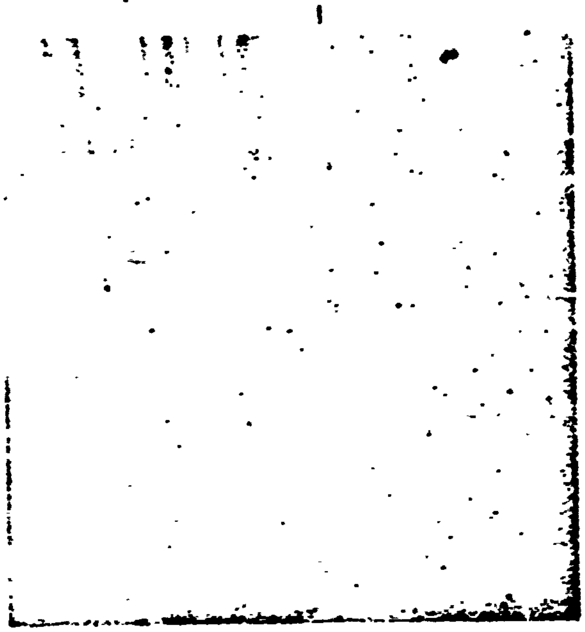
CHAPTER II

TEST FACILITY AND SPECIMEN PREPARATION

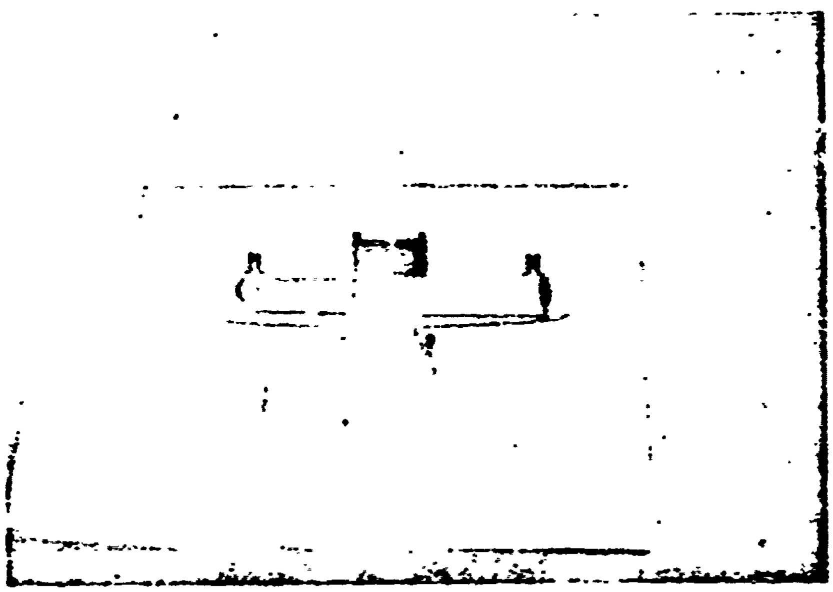
The exhorbitant cost and years associated with wire rope fatigue testing in the field favor accelerated laboratory tests. The resulting difficulty in interpreting results is offset by the greater control of important variables.

The test facility and anxilliary equipment used are illustrated in Figure 1. The test room, an accoustically isolated enclosure, contained a 22,000 lbs. capacity Amsler High Frequency Vibrophore, operating consoles, a temperature strip chart recorder and sea water exposure apparatus. The vibrophore operated on the resonance principle: the test frequency always coincided with the natural frequency of the vibrating mass. In this instance, the vibrating mass was composed of the specimen and the weight disks installed above the specimen. The mean load was applied by raising the cross arm while the fluctuating load was applied by an electromagnet. The load on the specimen was measured by an optical dynamometer and displayed on a scale. The machine calibration was checked by placing a load cell between the gripping heads in series with the machine dynamometer (See Appendix B). The Load Maintainer kept the mean load constant. A sensor on the cross arm and associated circuitry controlled the machine. A photocell feedback circuit,

Figure 1 TEST FACILITY



AMSLER HIGH FREQUENCY VIBROPHORE



TEN TON OPTICAL DYNAMOMETER

working in conjunction with the dynamometer light beam, kept the fluctuating load constant. A synchronous counter accumulated and displayed the number of applied cycles. The driving frequency was determined by the number of weights used and the specimen's own natural frequency. A preset and variable tuning control permitted operation at the resonant frequency. The frequency was calculated by noting the number of cycles during an elapsed period of time. The test frequencies used fell within the 60 to 120 Hz range.

Both the upper and lower gripping heads were restrained from rotating to prevent the wire rope from unlaying as the tensile load was applied. This point is mentioned since several testing machines such as certain hydraulic machines permit the lower gripping head to rotate.. A wire rope which becomes unlayed will have a much shorter axial fatigue life. Thus, the test condition imposed on the wire rope by the Amsler machine was representative of standing rigging on ships. It also is representative of certain towing harness configurations and mooring applications where both ends of the wire rope are restrained from rotating about the longitudinal axis.

Single Wire Specimen

The single wire axial fatigue tests were performed on 0.126 inch diameter wire of improved plow steel (IPS) used in the construction of 4 inch diameter wire rope. The wire was machine straightened, cut into ten inch lengths, and the ends

threaded to permit mounting in the machine as a bar specimen. To prevent failure in the grips, a circumferential circular groove was machined in the center of the gage length. The wire specimen configuration is shown in Figure 2.

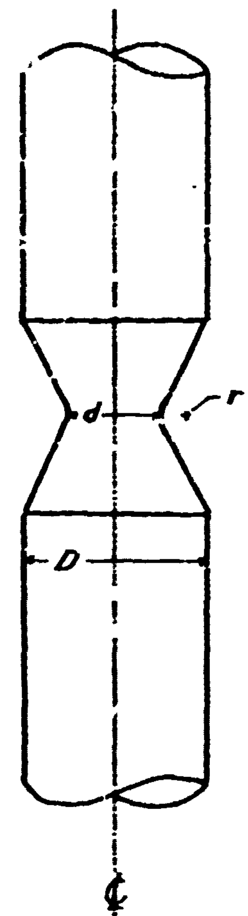
The root radius of 0.025 inches for the circumferential groove was selected on the basis of a preliminary test. In this pilot test series, the root radius was varied and the axial fatigue life measured at a fixed load spectrum. Upon reaching the bluntness of a 0.025 inch root radius, the groove no longer diminished the axial fatigue life. The loading spectrum for the main test series was based on the breaking load (BL) of 946 lbs. for the machined wire with the 0.025 in. notch.

Specimen tested in air were mounted soon after machining. The threaded ends of sea water specimen were covered with a clear plastic film. They were immersed for eighteen hours in test tubes filled with sea water.

1 x 25 Strand Specimen

The axial fatigue tests were performed on specimen prepared from IPS, ¼-inch diameter, 1 x 25 right lay preformed strand with a BL of 5,200 lbs. The strand was identical to that used in the construction of ½-in. 6x25 wire rope and was from the same heat of steel (See Appendix D) used in the ½-in. 6 x 25 wire rope. Specimen were cut from a 1,000 foot reel in 14 inch lengths. For the air tests, two inches on each end were cleaned in trichlorothene to remove the lubricant. Bushings machined

Figure 2 CONFIGURATION OF SINGLE WIRE SPECIMEN



Break Load 946 lbs.

d = 0.063 in.

D = 0.126 in.

r = 0.025 in.

K_t = 1.26

from 6061-T6 aluminum and annealed for two hours at 780F were pressed on the ends of the specimen using a 100 ton capacity hydraulic press. A pair of threaded adaptors were slipped on the specimen prior to pressing the second bushing. One half inch of strand extended beyond the pressed bushing on each end. These wires were spread apart and cleaned again in trichlorothene. A two-part Armstrong epoxy, C-7 resin, W activator, 1:1 ratio was applied to the end wires and cured for thirty minutes at 300F. Such epoxy reinforcement assured the specimen would not pull out of its aluminum grips. To complete the specimen preparation, aluminum bushings were machined to fit into the adaptors.

For the sea water tests, the 14 inch lengths of strand were cleaned with trichlorothene in the center of the gage length. The terminal three inches on both ends were covered with a clear plastic film. Then the strand length was immersed for forty-eight hours in test tubes filled with sea water.

<u>6 x 25 Wire Rope Specimen</u>

Wire rope specimen were prepared from four different 1,000 foot reels of ½-in. dia., 6 x 25W, IPS, BRT, FS rope. Two constructions of right Lang and left Regular, each with an Independent Wire Rope Core (IWRC) and Polypropylene (POLY) core were tested. The BL values supplied by the manufacturer were:

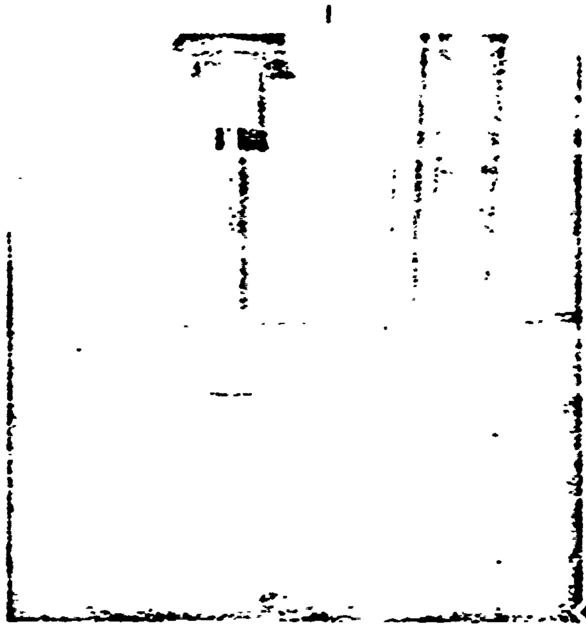
•Lang, IWRC	26,300 lbs.
•Lang, POLY	24,100 lbs.
•Regular, IWRC	25,700 lbs.
•Regular, POLY	22,800 lbs.

For both air and sea water tests, 14 inch lengths of the different wire ropes were prepared in the same manner as the strand. A completed wire rope specimen is shown in Figure 3. (Appendix C has additional drawings of the grips). The specimens for the sea water tests were placed in a rack where a stream of sea water flowed onto the center of the gage length. They were kept in the bath 48 hours and subsequently removed for testing.

Citgo Premium Wire Rope Compound was specified for closing the strand and wire rope (See Appendix D). This lubricant was selected after discussions with industry and Navy representatives who were not able to recommend a marine lubricant. The choice was based on the recent research effort of three wire rope lubricant manufacturers.

The gripping method used evolved after many unsuccessful attempts. Zinc poured open socket grips used in the field and in tensile breaking tests were not able to maintain their grip on the wire rope during the high frequency fatigue testing. The epoxy mix described earlier was not feasible as a sole method for gripping. Epoxy grips were adequate for tensile strength tests in breaking 3/8-inch diameter wire ropes. In fatigue tests, however, the socket geometry transmitted too much of the cyclic load energy to the epoxy, causing it to crumble. Consequently, the wire rope pulled out of the end grips.

Figure 3 WIRE ROPE SPECIMEN



SPECIMEN MOUNTED IN TEST MACHINE

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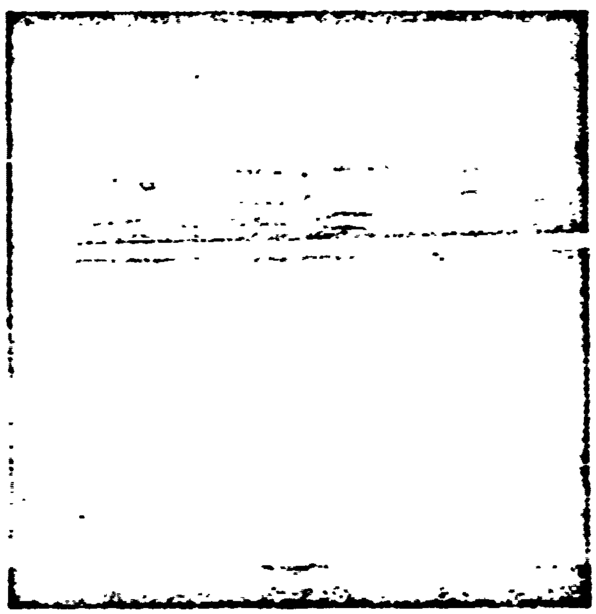


COMPLETED SPECIMEN

CHAPTER III

EXPERIMENTAL PROCEDURE

To enhance the possibility of detecting interrelations among wire, strand, and wire rope, the mean load and load range was a constant percentage of the specimens BL. Two mean loads of 20% and 30% for uncorroded specimens, and 20%,30%,40% and 45% BL for corroded specimens were combined with two load ranges of 30% and 40% BL. This permitted evaluation of the effect of mean load, load range, or their interaction. Wire, strand, and rope were tested first in air and then in sea water. The procedure for the single wires, strand, and wire rope was generally the same since all were fatigue tested on the same machine.

The specimens were mounted in the machine and subjected to the mean load. The corroded specimens were mounted within fifteen minuted after removal from their sea water bath. The air gap in the electromagnet was adjusted and the Load Maintainer set on automatic. The load range, fluctuating about the mean load, was applied and the feedback control circuit switched on. The cycle counter reading was noted and the running frequency calculated. After failure, the cycle counter value was recorded and the specimen removed. Slight variations in the test procedure associated with each type of specimen are discussed in the following sections.

Single Wire Tests

The failure of the single wire specimen was a complete fracture at the notch. At failure, the mean load and load range both dropped to zero. For the sea water tests, a three-inch long by one-inch diameter plastic tube was fitted onto the wire specimen and filled with sea water. The tube was positioned so as to center the circumferential groove in the sea water column.

1 x 25 Strand Tests

The failure of the strand occurred when enough wires had broken, usually more than three, to cause the natural frequency of the specimen to drop 5-10 Hz. A change in the natural frequency of this magnitude prevented tuning the driving frequency to obtain the required load range. The surface temperature of the strand was measured during testing.

In the sea water tests, an aluminum sleeve was placed around the mounted specimen. This sleeve was coated on the inside with plastic to prevent corrosion of the aluminum sleeve and cathodic protection of the strand. Sea water was pumped through the sleeve during the test at the rate of 4 gpm.

½-Inch Diameter 6 x 25 Wire Rope Tests

The 2^4 (four factors at two levels each) factorial design for the air and four levels of mean load for sea water experiments is shown in Table 1. After mounting, the wire rope specimen was preloaded to 40% BL for

Table 1 2^4 FACTORIAL DESIGN FOR ½-INCH WIRE ROPE

AIR TESTS

FACTOR	LEVELS															
A. Construction	Lang								Regular							
B. Core	IWRC				POLY				IWRC				POLY			
C. Load Range % BL	30		40		30		40		30		40		30		40	
D. Mean Load % BL	20	30	20	30	20	30	20	30	20	30	20	30	20	30	20	30
Replications	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

SEA WATER TESTS

A. Const	Lang															
B. Core	IWRC								Poly							
C. L. R.	30				40				30				40			
D. M.L.	20	30	40	45	20	30	40	45	20	30	40	45	20	30	40	45
Replicatns.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

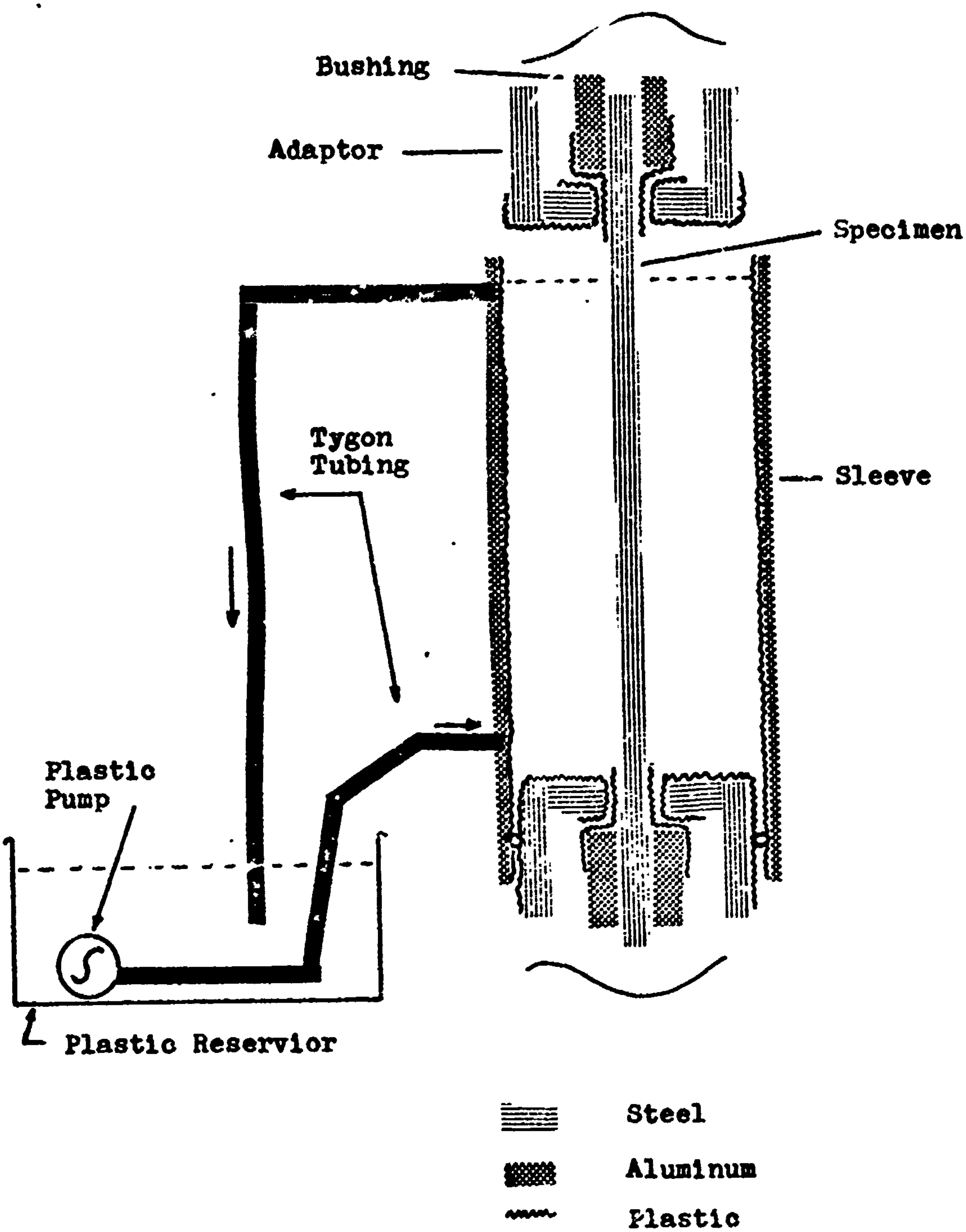
A. Const	Regular															
B. Core	IWRC								Poly							
C. L. R.	30				40				30				40			
D. M.L.	20	30	40	45	20	30	40	45	20	30	40	45	20	30	40	45
Replicatns.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

thirty minutes to reduce scatter in the data. Heat generated during air testing was measured on the surface of the wire rope. The heat softened the polypropylene core and necessitated the use of a cooling sleeve on the POLY core ropes. A non-corrosive antifreeze (Dow Therm 209) was pumped through the sleeve to maintain the surface temperature below 70C. Again, failure of a rope occurred when the drop in natural frequency prevented tuning the driving frequency to obtain the required load range. As before, an aluminum sleeve surrounded the specimen during the sea water tests. A schematic of the sea water flow and cross-section of the mounted specimen and sleeve are shown in Figure 4. This setup limited galvanic corrosion to the specimen. No cathodic protection was provided by the aluminum sleeve, end rip, or other components exposed to sea water.

3/8-Inch Diameter 6 x 25 Wire Rope

A small number of selected 3/8-inch diameter 6 x 25, IPS and SS wire rope specimens, while not part of this contract were tested in axial fatigue for the THEMIS Program during the contract period to determine the effect of immersion in the Atlantic Ocean off Connecticut and the results are reported here for information. All specimens were gripped in the same manner as the ½-inch diameter rope. One virgin specimen was tested in air as were four which has undergone two months and fourteen which had undergone six month immersion in the ocean. Two of the six month immersion specimens were unloaded during immersion, the rest were preloaded to 5700 lbs. during immersion. An additional virgin specimen was prepared and tested in the same manner as the ½-inch diameter wire rope sea water specimen. All specimens were tested at a mean load of 14% BL and load range of 25% BL, based on a BL of 14,000 lbs.

Figure 4 SEA WATER FLOW SCHEMATIC DURING AXIAL FATIGUE TESTING



Synthetic Sea Water

The sea water used in these tests was made from synthetic sea salt designated ASTM, D-1141-52. City tap water was passed through a multiple bed demineralizer which deionized the water. Forty-two grams of sea salt were mixed with ten liters of deionized water yielding ten liters of 3.5%, by volume, synthetic sea water. Sea water was prepared daily to minimize chemical changes. It was changed four times each twenty-four hour period in the corrosion bath for wire ropes and changed for each test on the Amsler Vibrophore.

One disadvantage of using synthetic sea water was the absence of marl deposits on the corroded specimen. Marl, a white deposit formed on metal surfaces, results from the decay of marine life present only in actual sea water. It is conceivable such deposits could mix with the wire rope lubricant and act as an abrasive substance during cyclic loading to shorten fatigue life.

CHAPTER IV

RESULTS AND DISCUSSION

The effect of load and environment on axial fatigue resistance is examined for single wires, strand, and wire rope. The effect of construction and core for wire rope also is evaluated.

Single Wires

The axial fatigue life of single wires tested in air and sea water is shown in Table 2. The strong effect of load range on the air results is demonstrated with a 96% difference between the two levels. The load range effect remained in the sea water results where fatigue life at 30% BL was 56% greater than that at 40% BL. In air, the mean load had a noticeable effect on fatigue life only at the lower load range with a 95% difference The data appear reversed under the higher load range with a -48% difference between mean load levels. This unexpected result may be due to slight differences in the machined notch which were magnified at the higher loading condition. Pitting of the sea water specimen reduced fatigue life by 91%, eliminating the mean load effect. Figure 5 displays the cycles to failure in air and sea water of the notched wire specimen.

The wire break in both air and sea water tests exhibited the characteristic fatigue fracture surface oriented perpendicu-

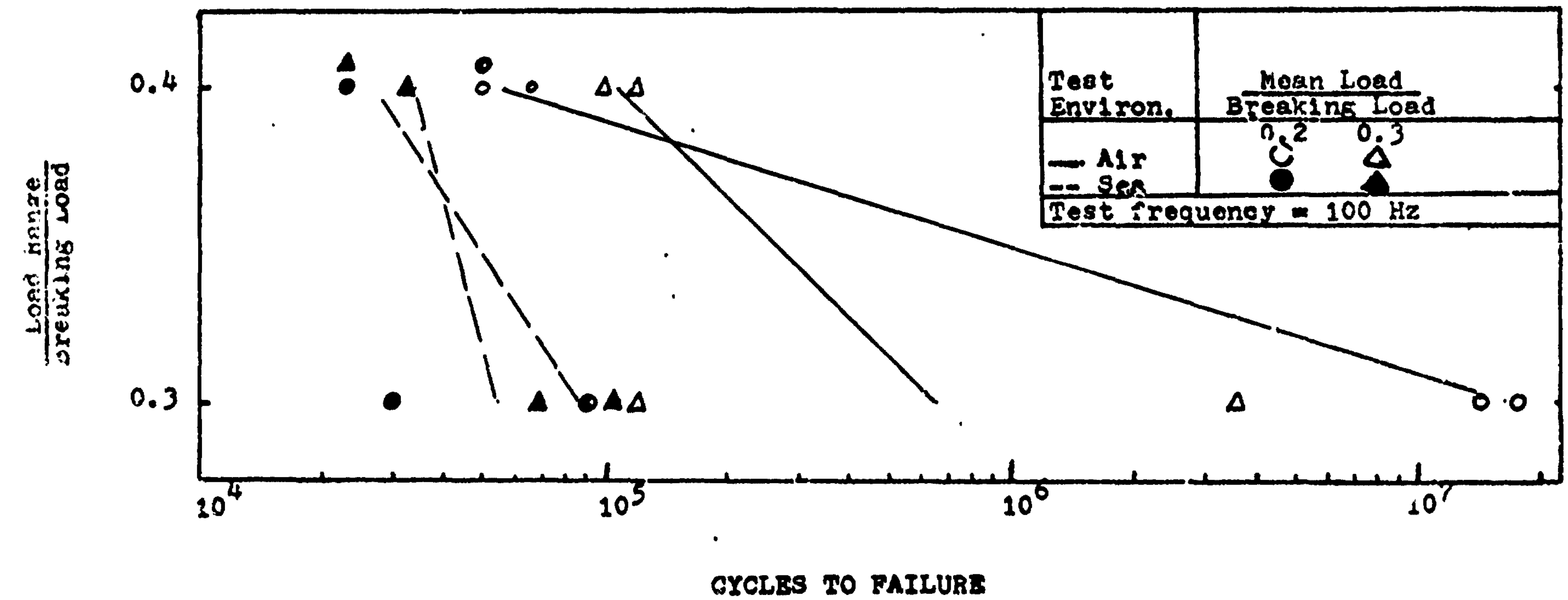
Table 2

AXIAL FATIGUE LIFE OF SINGLE WIRES IN MILLIONS OF CYCLES

Load Range	30% BL		40% BL	
Mean Load	20% BL	30% BL	20% BL	30% BL
AIR TESTS				
Two	14.360	3.600	0.050	0.123
Replications	18.303	0.121	0.067	0.100
Geometric Mean	16.028	0.660	0.057	0.110
Pooled Geometric Mean	3.252		0.080	
	0.510			
SEA WATER TESTS				
Two	0.030	0.112	0.050	0.032
Replications	0.091	0.069	0.023	0.023
Geometric Mean	0.052	0.088	0.034	0.027
Pooled Geometric Mean	0.068		0.030	
	0.045			

Figure 5

AXIAL FATIGUE LIFE OF NOTCHED
0.126-IN. DIA. IPS, BRT WIRE



larly to the wire's longitudinal axis. The fracture surface was granular with a bright faceted appearance, resulting from the slow propagation of the fatigue crack. A small crescent-shaped portion of the fracture surface, adjacent to the wire's outer surface, was fibrous and dull, the result of a rapid, ductile shear failure at separation. Pits could be seen on the perimeter of the fracture surface for sea water specimens. The fatigue crack was usually initiated at the largest pit.

1 x 25 Strand

The results of strand tests in air and sea water are displayed in Table 3. The fatigue life was 60% lower at the 40% BL load range than at 30% BL in both air and sea water results. At the higher load range of the air tests, the mean load effect was present with a 68% drop in fatigue life. The effect of sea water corrosion on the strand is only present at a mean load of 20% BL for both levels of load range. This is reasonable since as the total load is increased, the corrosion attack becomes less important in reducing fatigue life. The total load of a mean load equal to 30% BL and a load range equal to 30% BL or 40% BL was solely responsible for propagating the fatigue crack. The corrosion attack only contributed pitting for the initiation of the fatigue crack. Under a lower total load condition, the corrosion attack not only provided initiation sites but contributed to the fatigue crack propagation. A possible reversal of the mean load effect appears in the sea water data at the lower load range with a -36% difference.

Table 3

AXIAL FATIGUE LIFE OF 1X25 STRAND IN MILLIONS OF CYCLES

Load Range	30% BL		40% BL	
Mean Load	20% BL	30% BL	20% BL	30% BL
AIR TESTS				
Two	0.387	0.236	0.262	0.053
Replications	0.383	0.400	0.210	0.104
Geometric Mean	0.385	0.307	0.235	0.074
Pooled Geometric Mean	0.344		0.132	
	0.213			
SEA WATER TESTS				
Two	0.181	0.310	0.099	0.100
Replications	0.182	0.263	0.111	0.060
Geometric Mean	0.181	0.285	0.105	0.077
Pooled Average Geometric Mean	0.227		0.090	
	0.143			

This may be explained by the tighter contact between strand wires at the higher mean load which reduced the surface area available for corrosion. The resulting fatigue life was then comparable to that in the air tests. The air and sea water strand data are plotted in Figure 6.

The fracture surface of the broken wires in the strands displayed the same characteristic fatigue failure appearance noted in the signle wire tests. Occasionally, a broken wire was found reduced in diameter (necked-down) at the break point as the result of a tensile failure. The wire breaks were located on the outer surface of the strand in the air tests. In the sea water tests, the wire breaks occurred along the bottom of the interwire valleys where pitting corrosion had initiated the fatigue crack.

The surface temperature of the strand during air testing is plotted in Figure 7 as a function of frequency for the two load ranges. Temperature was primarily dependent on load range. The surface temperature doubled during the minute preceding failure for two specimens. The rise in temperature of a strand just prior to failure in axial loading has been observed elsewhere (24).

Figure 8 compares the air strand data obtained here at The Catholic University of America (CUA) with that reported by Berteaux (13) at Woods Hole Oceanographic Institute (WHOI) and Reemsnyder (24) at Bethlehem Steel Corporation (BSC). This comparison shows the importance of specifying the failure site as well as the failure criteria.

Figure 6 AXIAL FATIGUE LIFE OF ½-IN. DIA.
1 x 25 IPS, BRT, FS STRAND

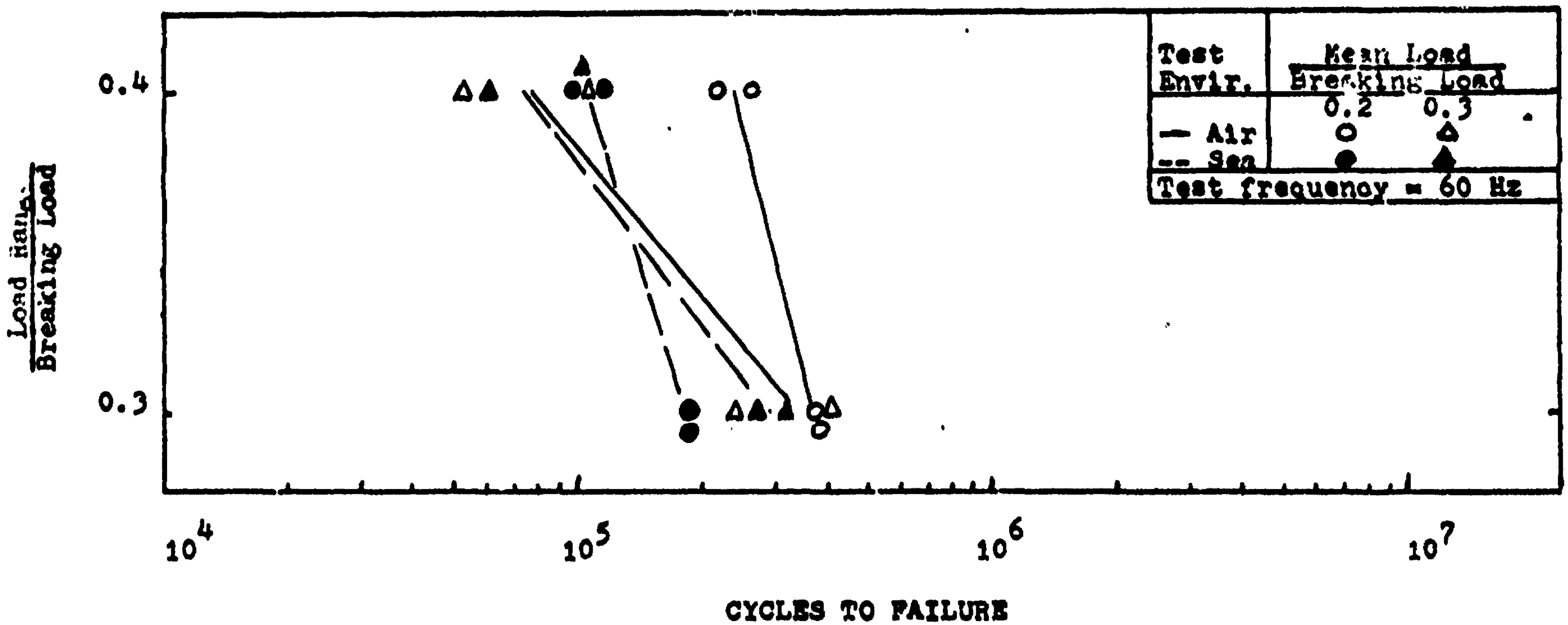
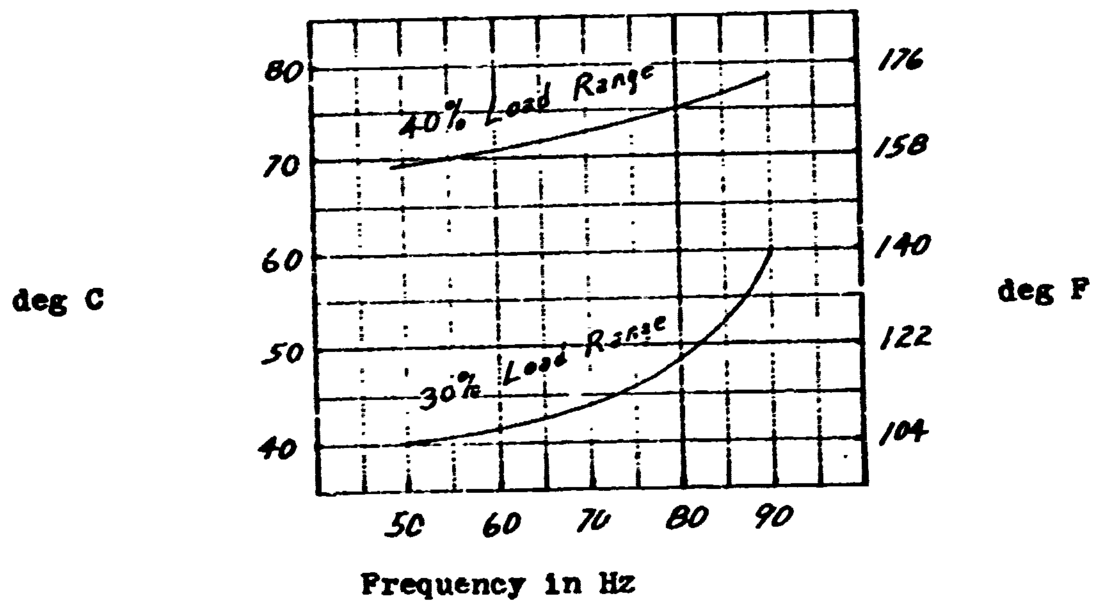


Figure 7 SURFACE TEMPERATURE AS A FUNCTION OF LOAD RANGE AND FREQUENCY

1 x 25 Strand



½-in. dia. 6 x 25 Wire Rope

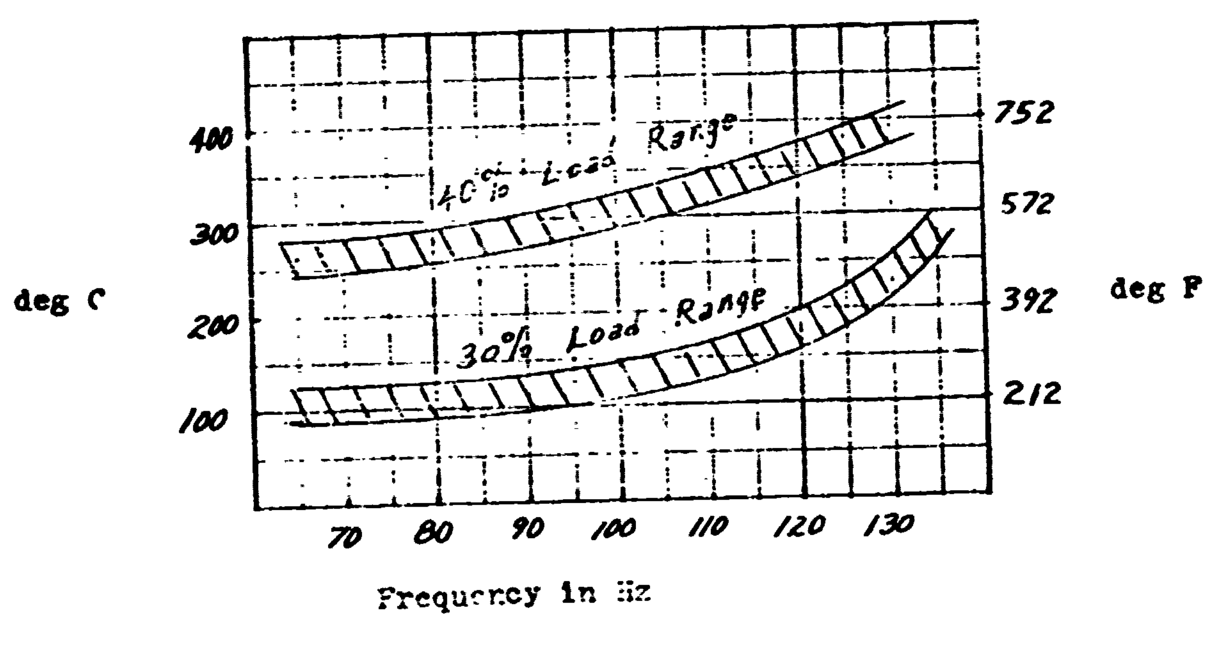
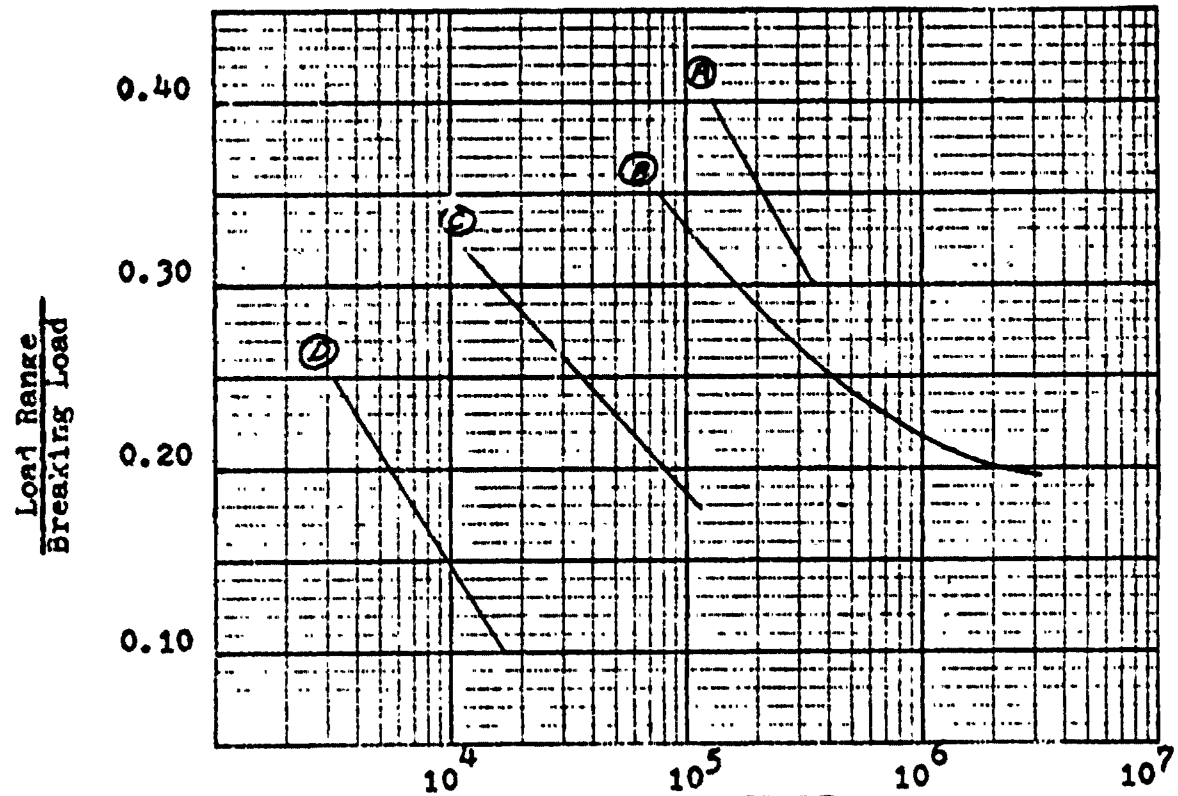


Figure 8 AXIAL FATIGUE LIFE OF STRAND IN AIR AS A FUNCTION OF LOAD RANGE



(A) CUA, ½-in. 1 x 25 strand, test freq. = 60 Hz, failure at 3-6 broken wires in gage length.
(B) BSC, 3/4-in. 1 x 37 strand, test freq. = 3 Hz, failure at 1st broken wire in gage length.
(C) BSC, ½-in. 1 x 19 strand, test freq. = 3 Hz, failure at 1st broken wire in grip.
(D) WHOI, ½-in. 1 x 25 strand, test freq. = 0.1 Hz, failure at 1st broken wire in grip.

Table 4 AXIAL FATIGUE LIVES OF WIRE ROPE IN MILLIONS OF CYCLES

A Construction	Lang								Regular							
B Core	IWRC				Poly				IWRC				Poly			
C Load Range	30% BL		40% BL		30% BL		40% BL		30% BL		40% BL		30% BL		40% BL	
D Mean Load (% BL)	20	30	20	30	20	30	20	30	20	30	20	30	20	30	20	30
Air Tests																
Two Replications	5.3	19.5	0.376	0.517	3.8	10.0	0.110	0.170	1.25	1.2	0.24	0.20	5.31	0.985	0.28	0.316
	16.1	10.0	0.481	0.600	3.5	2.4	0.190	0.258	1.5	2.5	0.291	0.291	13.6	4.79	0.97	0.280
Geometric Mean	9.45	13.96	0.425	0.557	3.64	4.9	0.144	0.208	1.37	1.73	0.264	0.241	8.50	2.17	0.521	0.298
Pooled Geometric Mean	11.358		0.487		4.227		0.174		1.540		0.252		4.296		0.351	
	2.351				0.858				0.623				1.228			
	1.420								0.875							
	1.115															
Sea Water Tests																
Two Replications	0.352	0.225	0.113	0.086	0.427	0.311	0.127	0.120	0.377	0.365	0.118	0.116	0.523	0.309	0.205	.144
	0.274	0.210	0.085	0.101	0.217	0.325	0.150	0.157	0.390	0.257	0.124	0.159	0.389	0.232	0.173	0.119
Geometric Mean	0.310	0.212	0.098	0.093	0.304	0.318	0.138	0.137	0.383	0.306	0.121	0.136	0.451	0.268	0.188	0.131
Pooled Geometric Mean	0.257		0.095		0.311		0.136		0.343		0.128		0.347		0.157	
	0.157				0.205				0.210				0.233			
	0.179								0.221							
	0.199															

Table 4 A AXIAL FATIGUE LIVES OF WIRE ROPE IN MILLIONS OF CYCLES

A Construction	Lang								Regular							
B Core	IWRC				Poly				IWRC				Poly			
C Load Range	30% BL		40% BL		30% BL		40% BL		30% BL		40% BL		30% BL		40% BL	
D Mean Load (% BL)	40	45	40	45	40	45	40	45	40	45	40	45	40	45	40	45

SEA WATER TESTS

Two Replications	0.366	0.262	0.107	0.072	0.340	0.222	0.171	0.140	0.197	0.198	0.164	0.098	0.222	0.172	0.118	0.111
	0.190	0.267	0.103	0.099	0.237	0.347	0.132	0.214	0.286	0.111	0.115	0.153	0.204	0.163	0.105	0.118
Geometric Mean	0.264	0.265	0.105	0.0844	0.284	0.278	0.150	0.179	0.237	0.148	0.137	0.123	0.212	0.167	0.111	0.115
Pooled Geometric Mean	0.264		0.0941		0.281		0.166		0.188		0.130		0.189		0.113	
Pooled Geo. Mean with Table 4	0.260		0.096		0.296		0.150		0.251		0.129		0.255		0.133	
Pooled Geometric Mean	0.157				0.211				0.180				0.184			
	0.182								0.1[illegible]							
	0.182															

½-Inch Wire Rope

Results of the ½-inch diameter wire ropes are displayed in Table 4. The load range effect was pronounced for all four types of ropes in both environments. The data do not show a mean load effect. The reversed ordering of the geometric mean values for the IWRC and POLY cores indicates that neither core by itself affects the fatigue life of the rope. In this analysis, it is assumed that use of the coolant in the air tests of POLY core ropes did not affect the fatigue life of the rope. This assumption is based on the idea that fatigue damage was affected by the friction and heat at contact points between wires and not by the heat which flowed away from the friction points. The corrosion attack produced an 82% drop in the axial fatigue life of the pooled geometric mean from the air results. The wire rope data are plotted in Figure 9.

The design of the wire rope experiment was made with the intention of performing a 2^4 factorial analysis of variance (ANOVA) on the data (25). The ANOVA determines the statistical significance of the effects of test variables (factors) and their interactions. Then one is allowed to draw a conclusion about an effect while knowing the probability that the conclusion is erroneous. The ANOVA was performed on the logarithms of the fatigue lives and a summary is presented in Table 5. Column "p" records the probability level at which the null hypothesis (no effect from this factor) can be rejected. The "p" value also is defined as the risk of rejecting the null hypothesis when it is true; i.e., committing a Type I error. The significance column shows the author's willingness to take only a risk equal to or less than 1 in 1000 (0.001) of making a Type I error;

FIGURE 9

AXIAL FATIGUE LIFE

½" DIA. 6X25 W, IPS, BRT, FS ROPE

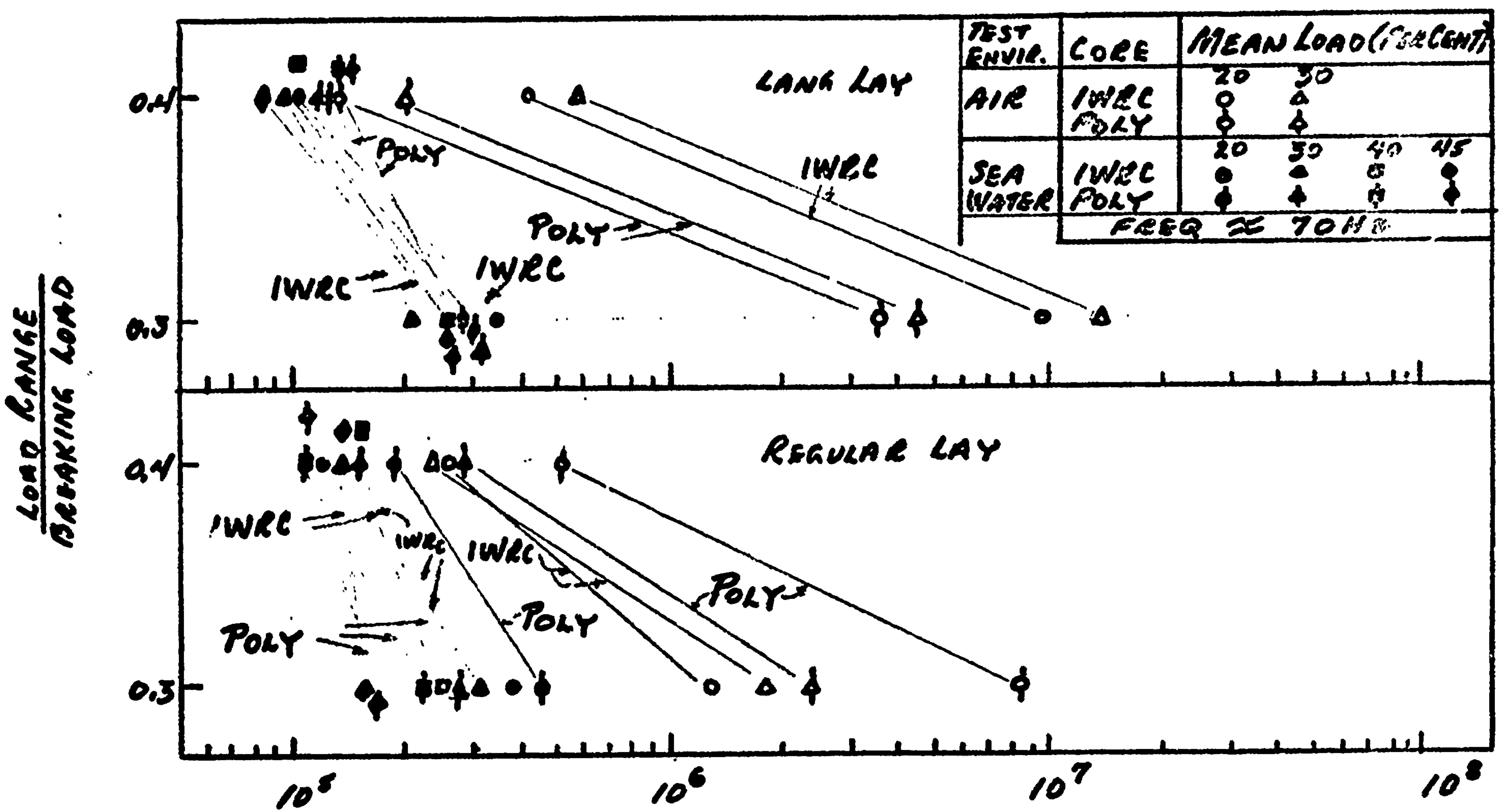


Table 5 ANOVA SUMMARY

Source of Variation	D.F.	Sums of Squares	Mean Squares	F Ratio	p*	Significant
Air Tests						
A, Construction	1	00.24476	00.24476	4.0984	0.10	
B, Core	1	.05406	.05406	.9052	< .10	
C, Load Range	1	10.89535	10.89535	182.4405	.001	Yes
D, Mean Load	1	.00350	.00350	.0586	< .10	
AxB Interaction	1	1.28936	1.28936	21.5900	.001	Yes
AxC "	1	.52192	.52192	8.7394	.01	
AxD "	1	.23795	.23795	3.9844	.10	
BxC "	1	.06531	.06531	1.0936	< .10	
BxD "	1	.09800	.09800	1.6409	< .10	
CxD "	1	.00491	.00491	.0822	< .10	
AxBxC "	1	.01035	.01035	.1733	< .10	
AxBxD "	1	.10384	.10384	1.7387	< .10	
AxCxD "	1	.00585	.00585	.0979	< .10	
BxCxD "	1	.04592	.04592	.7689	< .10	
AxBxCxD "	1	.01758	.01758	.2943	< .10	
Error	16	.95556	.05972			
Total	31	14.55420				
Sea Water Tests						
A. Construction	1	.0007	.0007	.0075	<0.10	
B. Core	1	.07114	.07114	7.7074	.01	
C. Load Range	1	1.73318	1.73318	187.7768	.001	Yes
D. Mean Load	3	.16514	.05505	5.9642	.005	
AxB Interaction	1	.05294	.05294	5.7356	.025	
AxC "	1	.02581	.02581	2.7963	.10	
AxD "	3	.13974	.04658	5.0465	.005	
BxC "	1	.02349	.02349	2.5449	0.10	
BxD "	3	.01849	.00616	0.6673	<.10	
CxD "	3	.08065	.02688	2.9122	.05	
AxBxC "	1	.01801	.01801	1.9512	<.10	
AxBxD "	3	.04289	.01430	1.5492	<.10	
AxCxD "	3	.03311	.01104	1.1960	<.10	
BxCxD "	3	.00898	.00299	.3239	<.10	
AxBxCxD "	3	.02450	.00817	.8851	<.10	
Error	32	.29528	.00923			
Total	63	2.73342				

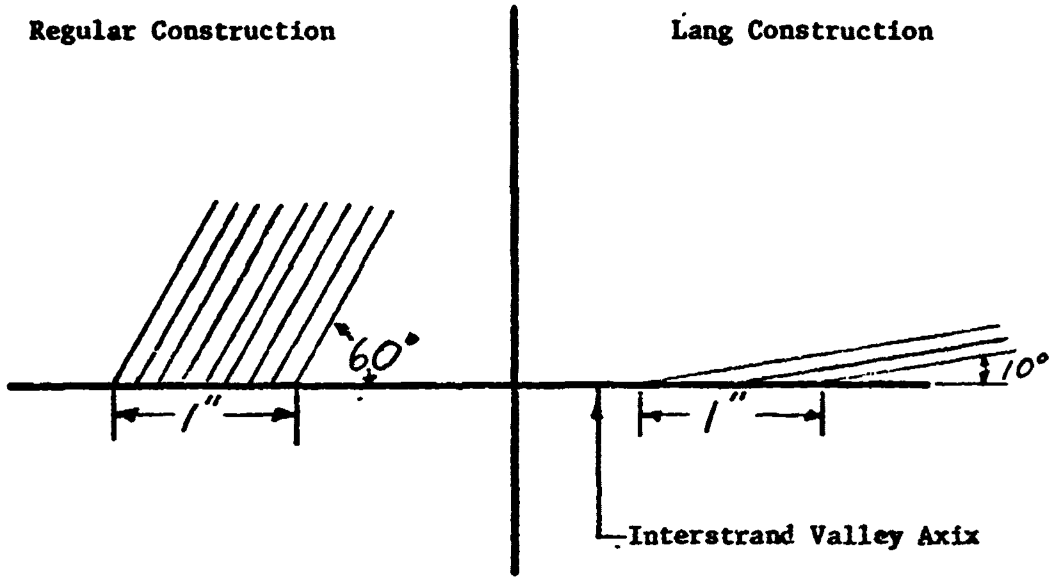
* p gives the probability level at which the null hypothesis can be rejected, also described as the risk of rejecting the null hypothesis when it is true; i.e. committing a Type I error.

i.e., claiming an effect when none exists. Such a presentation allows the reader to make an opinion about the significance of an effect based on personal experience which dictates one's risk taking attitude (26).

The ANOVA summary for the air data demonstrates that the effect of load range is significant. The construction-core interaction also is significant, showing that construction and core affected fatigue life, but not independently. The IWRC core performed best with Lang construction while the POLY core performed best with Regular construction.

The ANOVA summary for the sea water tests again finds load range to be significant. The construction-core interaction effect was not significant in the sea water tests. Construction - mean load interaction and mean load were almost significant.

The possible effect of construction suggests interstrand pitting was affected by the alignment of single wires with respect to the interstrand valley. In Regular construction, the strand wires run roughly parallel to the center line of the rope. They enter the interstrand valley at about a sixty-degree angle with the valley axis. The exact angle depends on the ropes lay angle. In Lang construction, the strand wires enter at approximately a ten-degree angle. As shown in the following sketch, there are about four times as many wires intersecting the valley axis per unit length in Regular construction as in Lang construction. This means the corrosion along the valley axis per unit length is distributed over four wires for Regular construction, but concentrated on only two wires for



Lang construction. This difference in interstrand corrosion may explain the observed difference in fatigue life.

3/8 Inch Diameter Wire Rope

The axial fatigue results of selected 3/8-inch diameter wire rope are presented in Table 6. The idea suggested by these data is that immersing wire rope in the ocean for two to six months, both loaded and unloaded, has an effect on its axial fatigue resistance. Inspection of the immersed ropes prior to testing disclosed that the protective lubricant was still there. Pitting corrosion was not evident in the interstrand valleys. This view was supported when the failed ropes were inspected. While two months immersion showed negligable effect on the fatigue life of the 3/8"IPS wire rope specimens, those immersed for longer periods did show a noticable reduction in fatigue life. The results for stainless steel wire rope were inconclusive. The specimens that were loaded during immersion showed longer fatigue life which leads to the conclusion that the strands were held more tightly together and therefore tended to prevent the entry of seawater which resulted in less interstrand corrosion.

TABLE 6. RESULTS OF AXIAL FATIGUE TESTS ON SELECTED 3/8 INCH DIAMETER WIRE ROPE

Specimen	Material	Exposure	Pre-Load	Frequency	Air Temp.	Spec. Temp.	Cycles
1	IPS	None	None	111 HZ	$80^{o}F$	$145^{o}C$	$1.107X10^{6}$
2	IPS	48hrLab.	None	112 HZ	$82^{o}F$	$27^{o}C$	$0.343X10^{6}$
3	IPS	2 mos.	None	116 HZ	$81^{o}F$	$140^{o}C$	$1.003X10^{6}$
4	IPS	2 mos.	None	116 HZ	$80^{o}F$	$145^{o}C$	$1.158X10^{6}$
5	IPS	2 mos.	5700lbs.	116 HZ	$78^{o}F$	$130^{o}C$	$0.799X10^{6}$
6	IPS	2 mos.	5700lbs.	61 HZ	$79^{o}F$	$135^{o}C$	$1.216X10^{6}$
7	IPS	6 mos.	None	85 HZ	$78^{o}F$	$145^{o}C$	$0.528X10^{6}$
8	IPS	6 mos.	None	85 HZ	$74^{o}F$	$167^{o}C$	$0.593X10^{6}$
9	IPS	6 mos.	5700lbs.	89 HZ	$86^{o}F$	$148^{o}C$	$1.068X10^{6}$
10	IPS	6 mos.	5700lbs.	86 HZ	$78^{o}F$	$147^{o}C$	$0.701X10^{6}$
11	IPS	6 mos.	5700lbs.	83 HZ	$75^{o}F$	$170^{o}C$	$2.223X10^{6}$
12	IPS	6 mos.	5700lbs.	84 HZ	$75^{o}F$	$160^{o}C$	$0.760X10^{6}$
13	IPS	6 mos.	5700lbs.	76 HZ	$81^{o}F$	$150^{o}C$	$1.033X10^{6}$
14	IPS	6 mos.	5700lbs.	82 HZ	$85^{o}F$	$202^{o}C$	$0.499X10^{6}$
15	IPS	6 mos.	5700lbs.	84 HZ	$78^{o}F$	$172^{o}C$	$1.467X10^{6}$
16	IPS	6 mos.	5700lbs.	83 HZ	$73^{o}F$	$165^{o}C$	$0.906X10^{6}$
17	SS	6 mos.	5700lbs.	83 HZ	$84^{o}F$	$186^{o}C$	$0.385X10^{6}$
18	SS	6 mos.	5700lbs.	82 HZ	$78^{o}F$	$180^{o}C$	$0.366X10^{6}$
19	SS	6 mos.	5700lbs.	82 HZ	$82^{o}F$	$182^{o}C$	$.267X10^{6}$
20	SS	6 mos.	5700lbs.	79 HZ	$79^{o}F$	$185^{o}C$	$.241X10^{6}$

Notes:

1. Breaking Load 14,000 lbs.
2. Mean Load 14% Breaking Load (0.9 Metric tons)
3. Load Range 25 % BL (0.1 - 1.7 Metric tons)
4. Exposure (except specimen #2) Long Island Sound, Preload during exposure
5. Exposure Specimen #2 48hrs Synthetic Seawater in Laboratory (cleaned)

One virgin 3/8-inch diameter specimen was prepared and tested in the same manner as the ½-inch diameter wire ropes which were tested in sea water. The 65% difference in fatigue life highlighted the effect of interstrand pitting.

Test Data in Perspective

Figure 10 permits easy comparison of the single wire, strand, and ½-inch diameter wire rope data. The pooled geometric means of the air and sea water data are plotted as a function of Load Range. In air, the fatigue life of strand is much lower than the fatigue life of single wires, a difference possibly attributable to the process of closing wires into strands. In sea water the pitting corrosion was more severe in the circumferential groove of the wire than in the interwire valleys of the strand even though the wire specimens were preimmersed for only 18 hours as opposed to the 48 hours of the strand. The single wire data in air is only comparable to that of Lang construction wire rope with a POLY core. Data plotted for mean loads of 20%, 30%, 40%, and 45% BL show that mean load is of small significance.

Figure 11 compares the axial and bending fatigue life of ½-inch dia., 6x25, IPS, wire rope tested in air. The data presented here is for Lang construction with a POLY core and Regular construction

Figure 10

AXIAL FATIGUE LIFE OF SINGLE WIRE, STRAND, AND WIRE ROPE

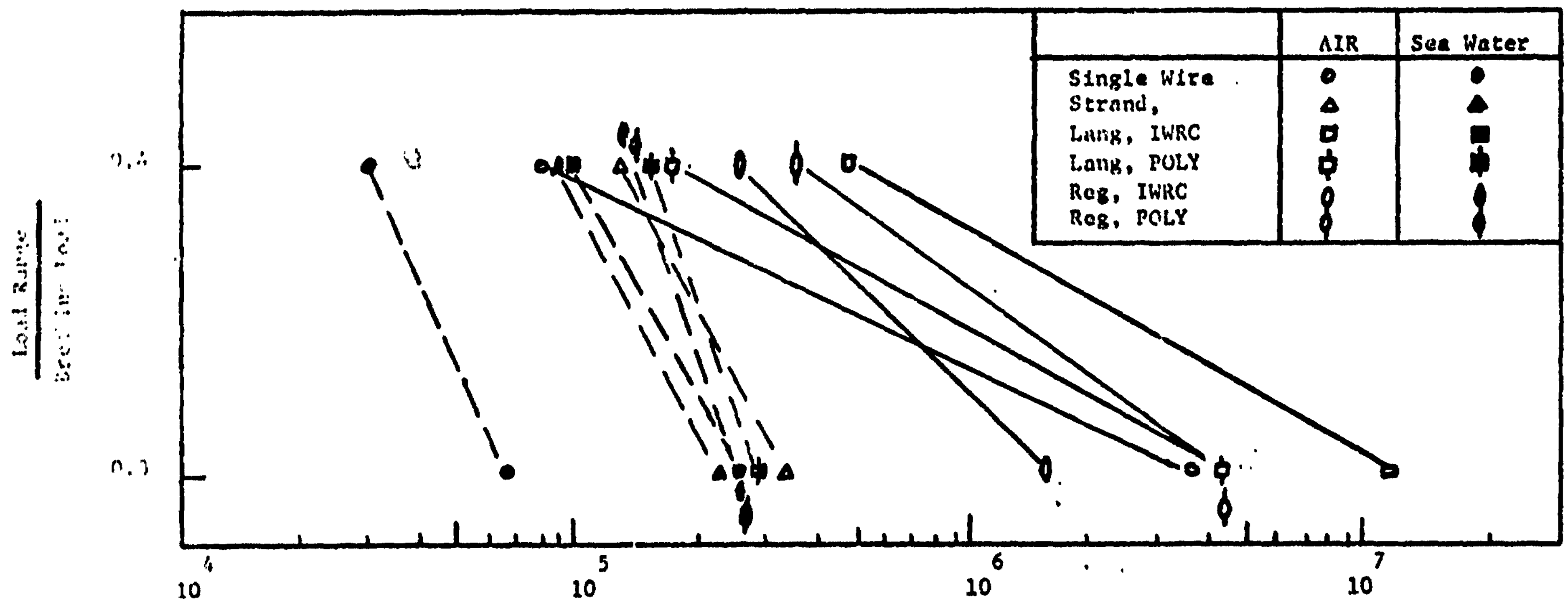
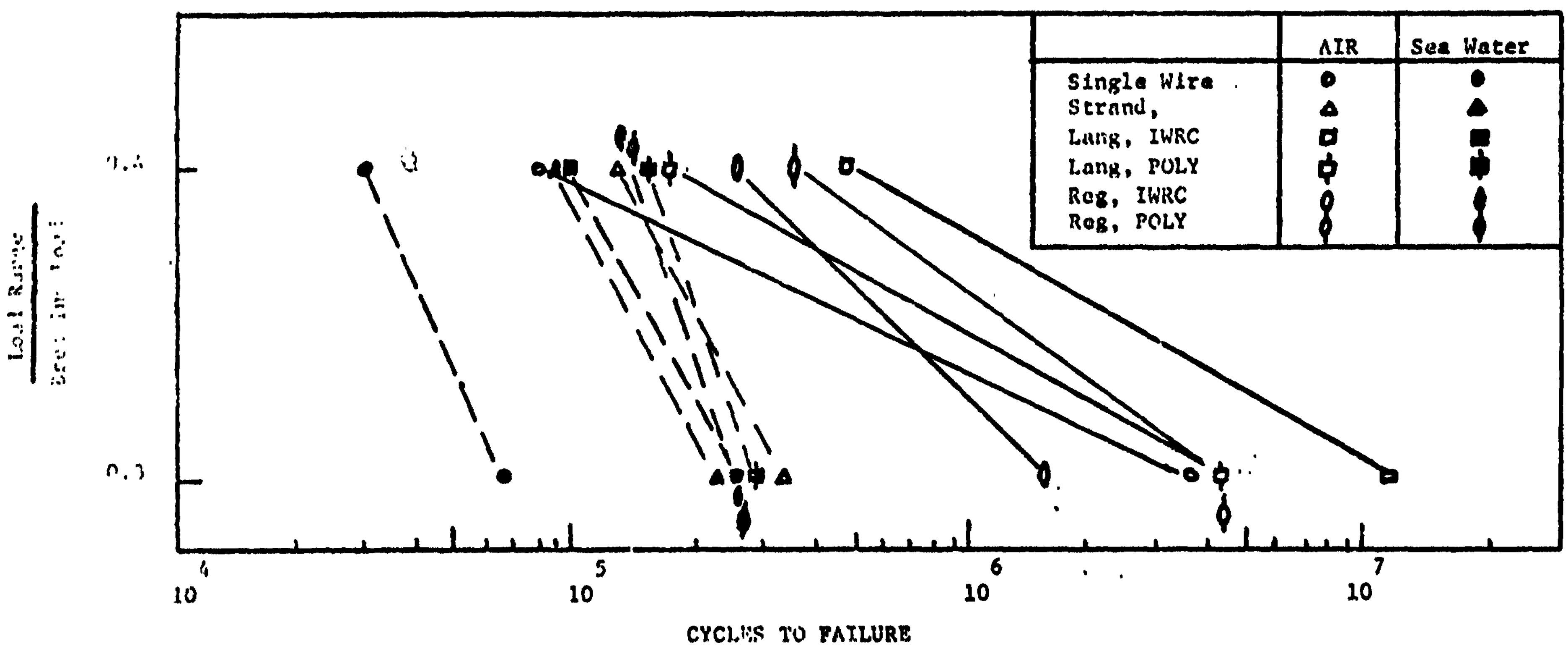


Figure 10

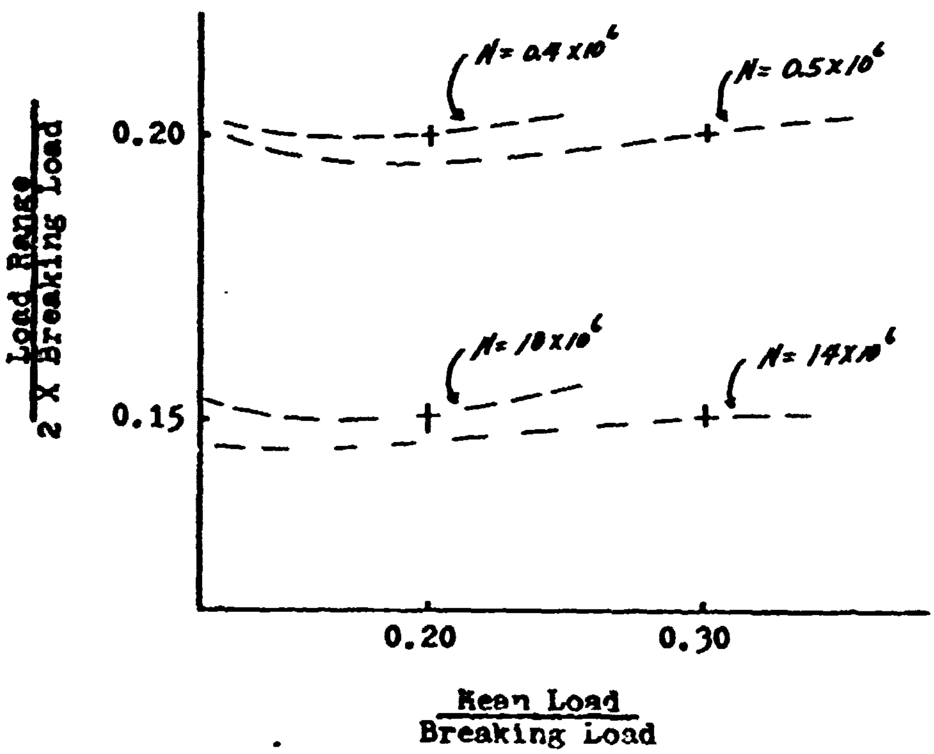
AXIAL FATIGUE LIFE OF SINGLE
WIRE, STRAND, AND WIRE ROPE



with IWRC core obtained in this study and reported by Gambrell (9). The limited data points indicate the relative severity of fatigue damage imposed by these two methods of loading at low levels. It also suggests that no difference may exist between these methods of loading at high levels.

Figure 12 shows the ½-in. dia. wire rope air data as function of Mean Load and Load Amplitude. The extrapolated trend lines again show that Mean Load had little effect on fatigue life. Additional data is necessary to plot actual fatigue life curves.

Figure 12 AXIAL FATIGUE LIFE OF ½-IN. DIA., 6 x 25, IPS, WIRE ROPE AS A FUNCTION OF MEAN LOAD AND LOAD AMPLITUDE



CHAPTER V

CONCLUSIONS AND SUMMARY

The conclusions of this experiment are based on axial fatigue testing in a laboratory, a limited number of specimens, the controlled use of pertinent variables and careful analysis of results. They are presented to assist users in the selection and replacement of wire rope. Manufacturers also may find ideas for improving wire rope design.

Conclusions

1. With respect to the axial load spectrum, the effect of mean load was not detected while the effect of load range is of paramount importance.

2. In air, the axial fatigue resistance of single wires exceeded that of strand for the four tests each (wire and strand) conducted at the lower load range. This was not true for the higher load range. Such an effect was not found between strand and wire rope results. The lower fatigue resistance of strand, compared to rope, limits its use in the prediction of wire rope performance.

3. The IWRC or POLY core of a wire rope does not affect fatigue life independently. The interaction with rope construction, however, has a significant effect in air, not significant effect in sea water. A POLY core performed best with Regular construction in air and in sea water. The IWRC core gives Lang constructed ropes the advantage in air.
4. In air, rope construction and core act jointly to determine fatigue life.
5. With prudent interpretation, the data presented can be used in formulating replacement criteria for wire rope.
6. Galvanic corrosion of wire rope exposed to sea water does not begin until the protective lubricant film is removed. Below the splash zone, this can mean many months of corrosion free operation as suggested by the 3/8-inch diameter rope data and by the Nomad mooring system (27).
7. Increased corrosion fatigue life of Lang constructed ropes might be obtained by changing the lay angle of wires in the strand.
8. Lang, IWRC wire rope is generally preferred for marine applications. Although it suffered a significant loss in fatigue life due to corrosion, it has the most to benefit from the proper lubricant, careful handling, and cathodic protection.

Summary

The axial fatigue life of wire, strand, and wire rope demonstrated a strong dependence on load range. It is presently not feasible to use either wire or strand for predicting the fatigue resistance of wire rope. Anticipated performance of wir· rope in the ocean should not be based on tests conducted in the air. Beside the straightforward detrimental effects of corrosion, other less obvious interactions can produce unexpected results. When ordering wire rope, the lubricant should be selected carefully. The corrosion protection it provides can increase greatly the useful life of a wire rope. If properly selected, wire rope can be expected to give reliable performance in the ocean over extended periods of time.

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Appendix A

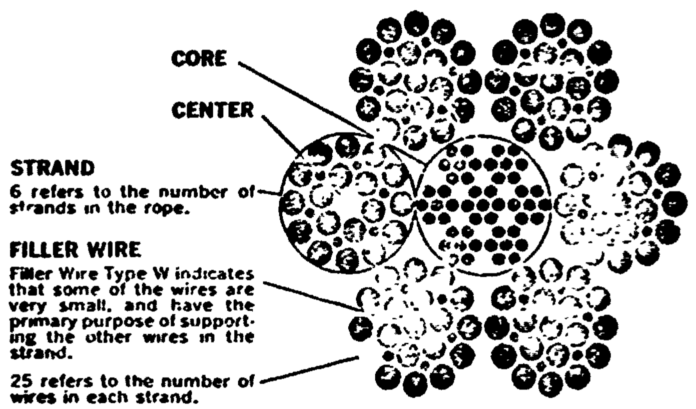
Definition of Wire Rope

Terminology

From Bethlehem Steel's Wire Rope Handbook

DEFINITION OF TERMS

Explanation of a few basic terms may be helpful to the user. We will use as our example one of the most common constructions, that of the 6 x 19 Class. The full, specific designation of our example is 6 x 25 filler wire Type W with IWRC, regular lay, Form-Set, Purple Strand.



Class—This is a nominal grouping of basically similar wire ropes having approximately the same number of wires in the strand, and the same number of strands per rope. The 6 x 19 Class is made up of wire ropes having anywhere from 15 to 26 wires per strand.

Construction — Wire rope is referred to first by the number of strands per rope, then by the number of wires per strand, then by the specific makeup of the strand, and finally the type of core, lay, and other information.

The rope is made up of 19-wire strands. The strands are each laid 12-6-1; that is, 12 outer wires, six inner wires, and one center wire. The six filler wires, of course, are in addition to these 19 wires.

IWRC — Independent wire rope core, around which the strands of the rope are laid.

Regular lay — Refer to the discussion of lay on page 6.

Center — Term applied to the center of a strand.

Form-Set — Bethlehem's trade name for preformed wire rope. Form-Set means that during manufacture the wires and strands have been preset in the helical shape they take in the rope. (More detailed description — page 4.)

Purple Strand — Indicates the strength grade of the steel, and is Bethlehem's trade name for improved plow steel.

Strand—Strand is made of wires, and is usually referred to by the number of wires it contains. Thus, a 7-wire strand has 6 wires laid around a single, center wire.

GRADES OF WIRE ROPE

While there are many different grades of wire rope, the vast majority of ropes fall into one of the categories described below. The others fill highly specialized requirements.

Purple Plus — Bethlehem's trade name for *extra improved plow steel*, the strongest rope available. Usually identified with *two* Purple Strands.

Purple Strand — Bethlehem's trade name for *improved plow steel*, used for most operating applications. Usually identified with *one* Purple Strand.

Plow—Formerly the basic grade of wire rope, this grade is now only specified where service requirements are not severe.

Aircraft—Aircraft rope and strand are made to a special strength grade, usually referred to as "Aircraft Grade."

Elevator ropes—The various ropes used for elevators are discussed in detail on page 80. The special grades manufactured by Bethlehem for elevator use are Extra High Strength Traction Steel, High Rise Special Traction Steel, Traction Steel, and Iron.

FORM-SET

Form-Set is Bethlehem's trade name for preformed wire rope. Form-Set means that the wires and strands have been preset during manufacture into the permanent helical shape they take in the completed rope. **Unless otherwise specified, wire ropes are normally furnished Form-Set.**

Preforming greatly reduces internal stresses; eases rope handling. Cut ends need not be seized or served to prevent unwinding. Preformed ropes run smoother and truer than non-preformed, are less susceptible to bending fatigue, and give longer service life.

WIRE ROPE CORES

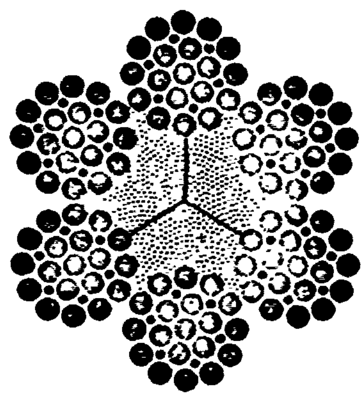
The term *core* applies only to the center of a wire rope. There are many kinds of cores, some of which are listed below. The primary purpose of the core is to support the strands of the rope during its service life.

Fiber core—Either of Polypropylene or other fibrous plastic material, or of fibrous vegetable material. In the latter case, the core closely resembles the familiar manila rope. Fiber core material is chosen for toughness and resilience, rather than strength.

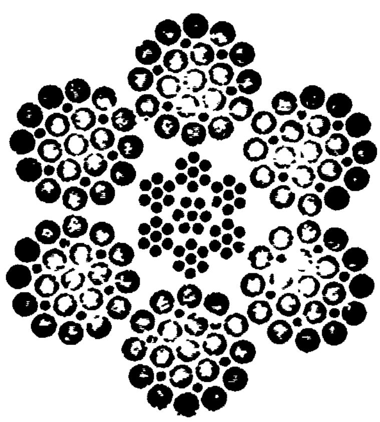
Independent wire rope core (IWRC)—IWRC may be either a 6 x 7 wire rope with a fiber core or a 6 x 7 wire rope with a wire-strand core (7 x 7 wire rope). An IWRC is somewhat less flexible than fiber core, but has much greater resistance to crushing plus additional rope strength.

Wire strand core (WSC)—May or may not be of the same construction as the outer strands of the rope. The WSC gives the smoothest and most solid support for the outer strands, and is used where loads or bearing pressures are greatest. Ropes with WSC are the least flexible of all, and are seldom used on operating ropes.

Special cores—Made to suit special requirements of specific applications, their content and makeup vary widely.



Rope with fiber core.



Rope with an independent wire rope core, usually referred to as IWRC.

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EXPLANATION OF LAY

Lay is sometimes an undeservedly confusing wire rope term, and its meaning is important to know. Essentially, the term derives from the way in which the rope is put together. Contrary to first appearance, wire rope is *not twisted* together from wire and strand. Rather, it is *laid* in position. Indeed, great care is taken in the manufacture of wire rope to ensure that no twist is imparted to the wires or the strand.

The term lay is used in two ways.

1. To describe a rope's appearance or construction as regards the *direction* of its spiral.
2. In measuring the *length* of the spiral of the rope.

When used in the first context, the terms *right* and *left* refer to the way the strands rotate around the rope, and the terms *regular* and *lang* refer to the way the wires rotate in the strands in relation to the direction of the strands in the rope.

In *right* lay, strands rotate around the rope in a clockwise direction, as the threads do in a right-hand bolt.

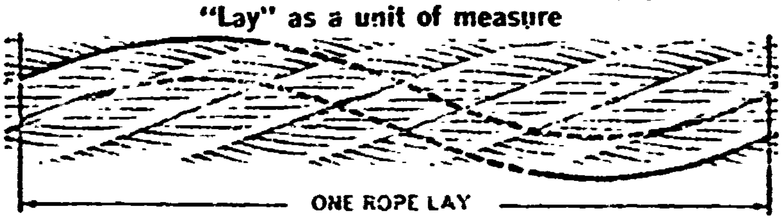
In *left* lay, the strands rotate counterclockwise, as in a bolt with left-hand threads.

Regular lay means that the wires in a strand rotate in a direction opposite to the direction in which the strand rotates around the rope. On a rope with strands laid to the right, "regular" would mean that the wires in each strand were laid to the left. The net result of regular lay is that the wires run roughly parallel to the center line of the rope. (Most users of wire rope are familiar enough with terminology to understand that when we say "regular lay," throughout this booklet, we imply "*right* regular lay." This is common practice throughout the industry. For those who may not be fully aware of this practice we have noted it at the bottom of all pages listing suggested ropes.)

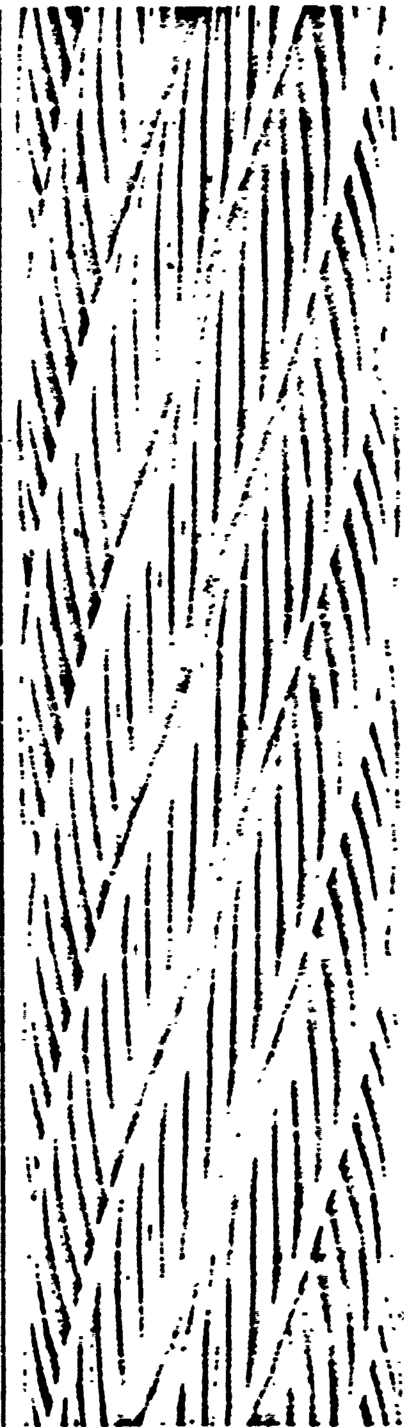
Lang lay is just the reverse of regular. Wires in a lang lay rope rotate in the same direction as the strands, giving the appearance of spiraling diagonally around the rope.

In its second meaning, as a unit of measure, rope *lay* means the lengthwise distance a single strand covers in making one complete turn around the rope. Lay length is measured in a straight line parallel to the center line of the rope, *not* by following the strand as it spirals around the rope. Lay length is directly related to rope diameter, providing a convenient basis for rope inspection. An example of the use of this would be in the requirement that a rope be removed from service after a certain number of wires are broken in one rope lay. Such a requirement would be more dependable than one requiring removal on the basis of broken wires per foot.

"Lay" as a unit of measure



Showing how "one rope lay" is the lengthwise distance in which a strand makes one complete turn around the rope.



Right regular lay.

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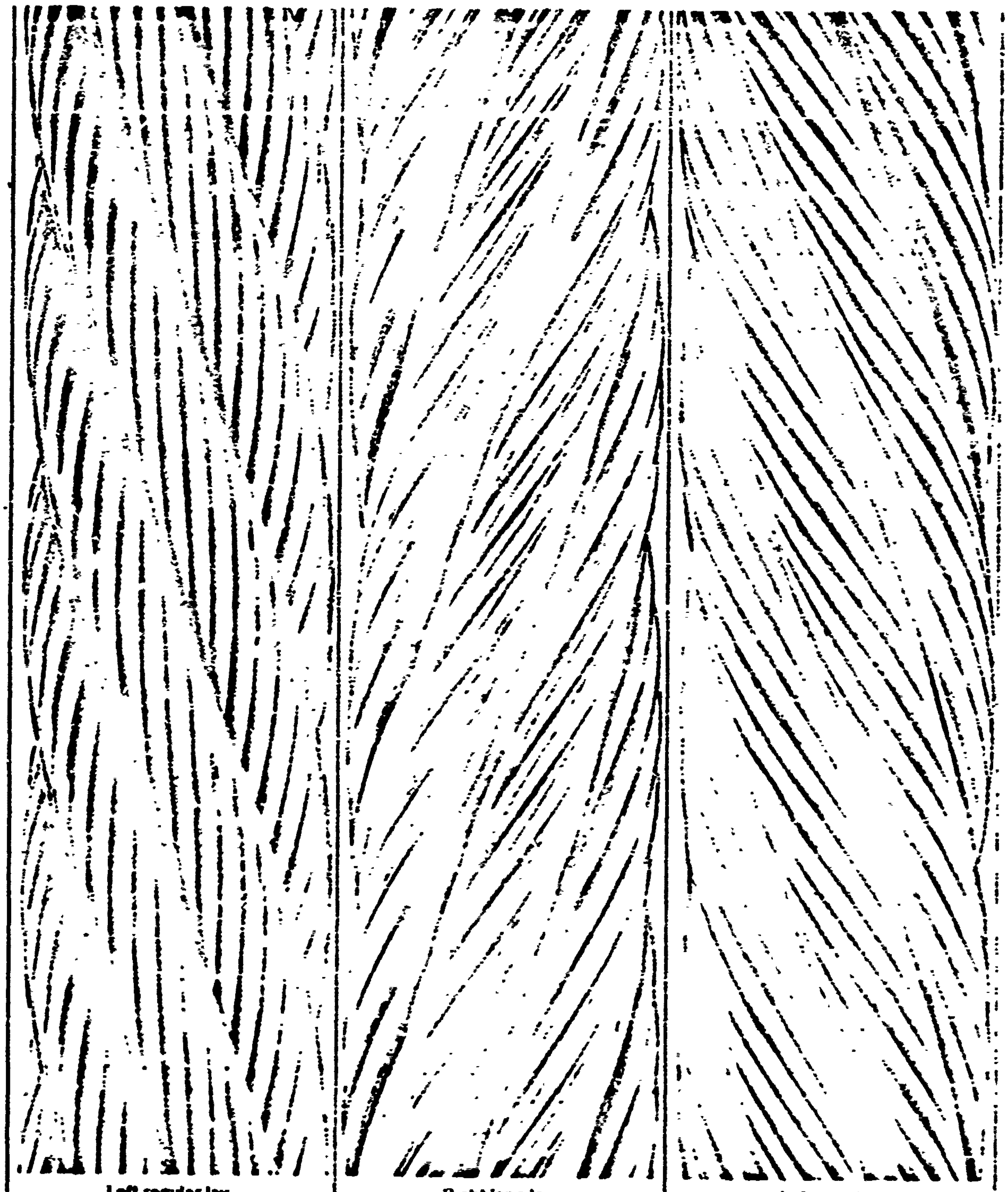
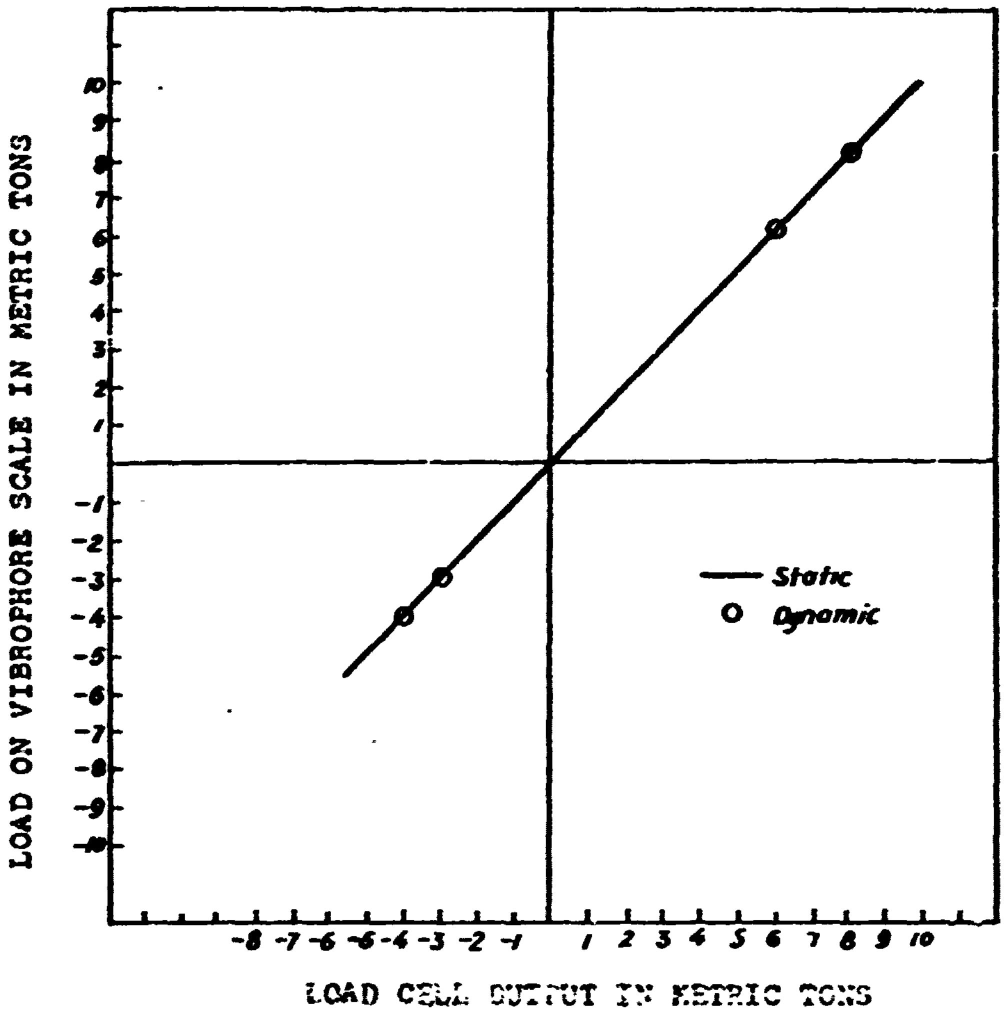


Left regular lay. Right lang lay. Left lang lay.

Appendix B

Calibration of Testing Machine

STATIC AND DYNAMIC CALIBRATION CHECK OF AMSLER VIBROPHORE TESTING MACHINE



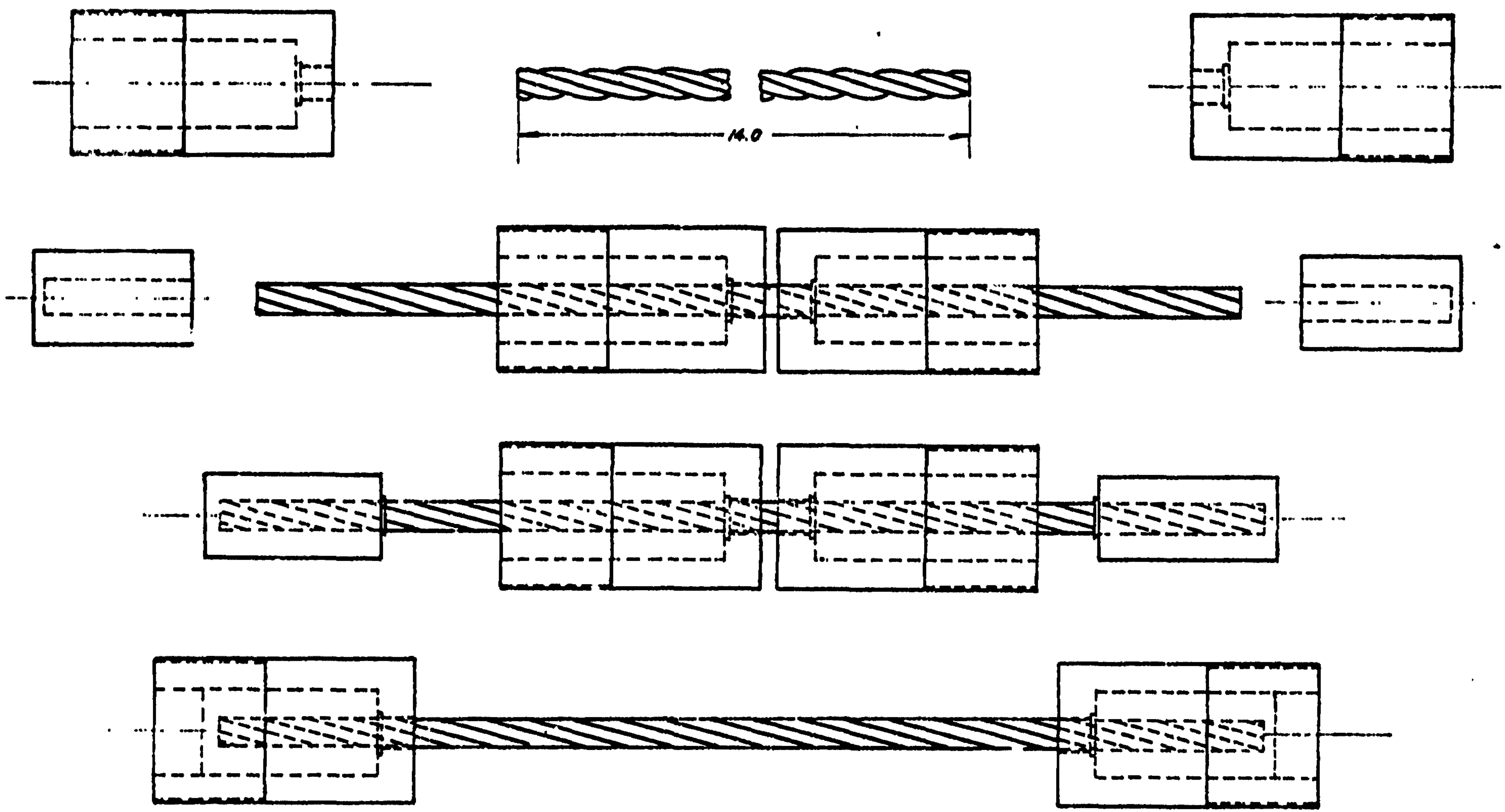
Calibration Procedure: Two different load cells were used to obtain all the calibration data points. One cell had a 10K capacity, the other 50K; both gave a 2 mv/v signal. The signal was processed by a Honeywell Accudata 105 Gage Control Unit and then fed into a Digital Voltmeter or an oscilloscope. The Digital Voltmeter yielded the static readings while the oscilloscope gave the dynamic readings.

Date: 15 Feb 1971

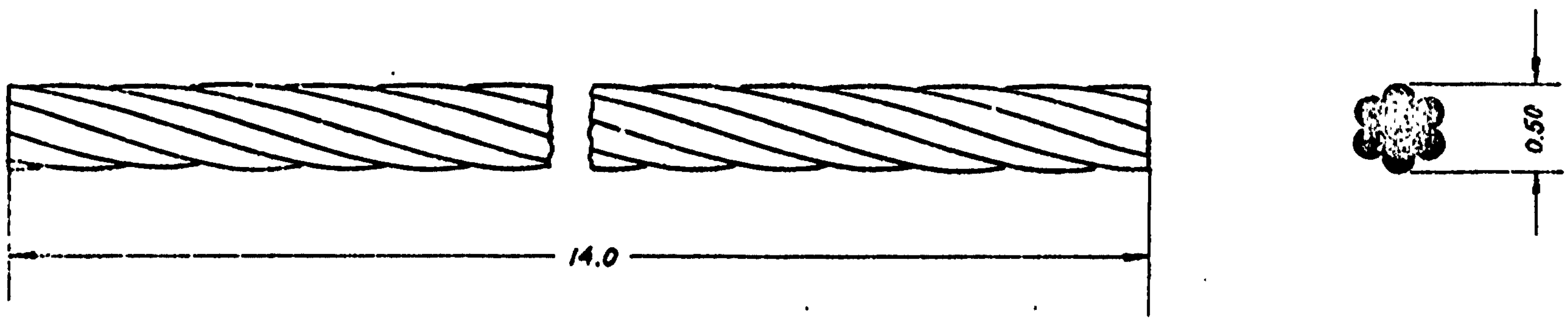
F. Malonzo

Appendix C

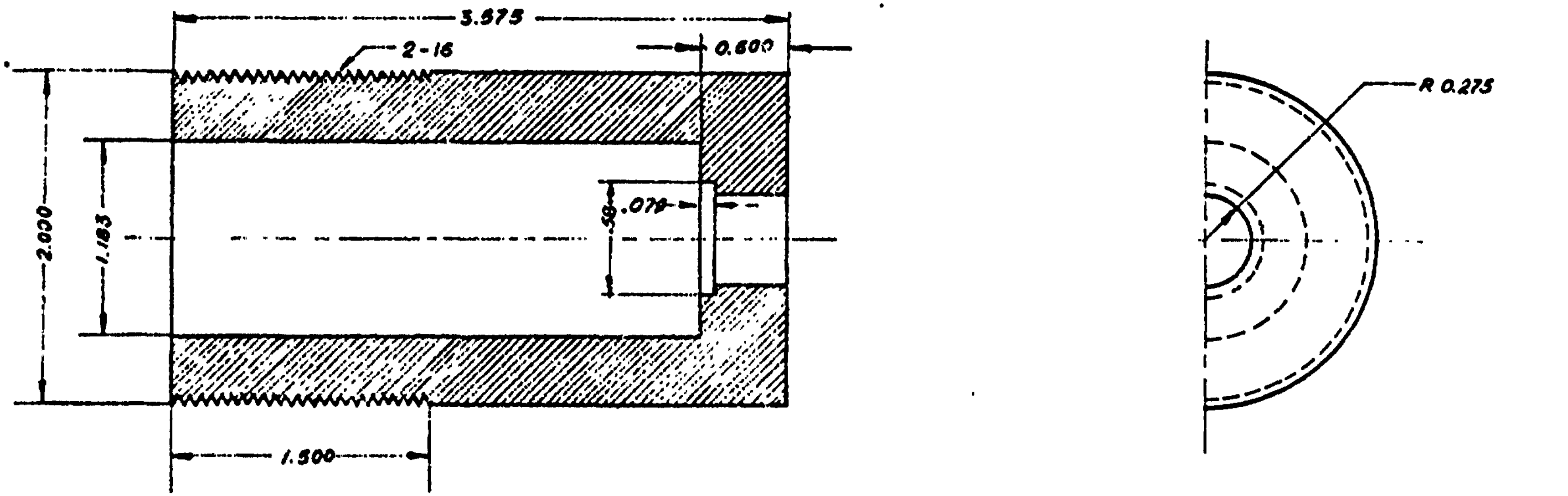
Preparation of Wire Rope Specimen



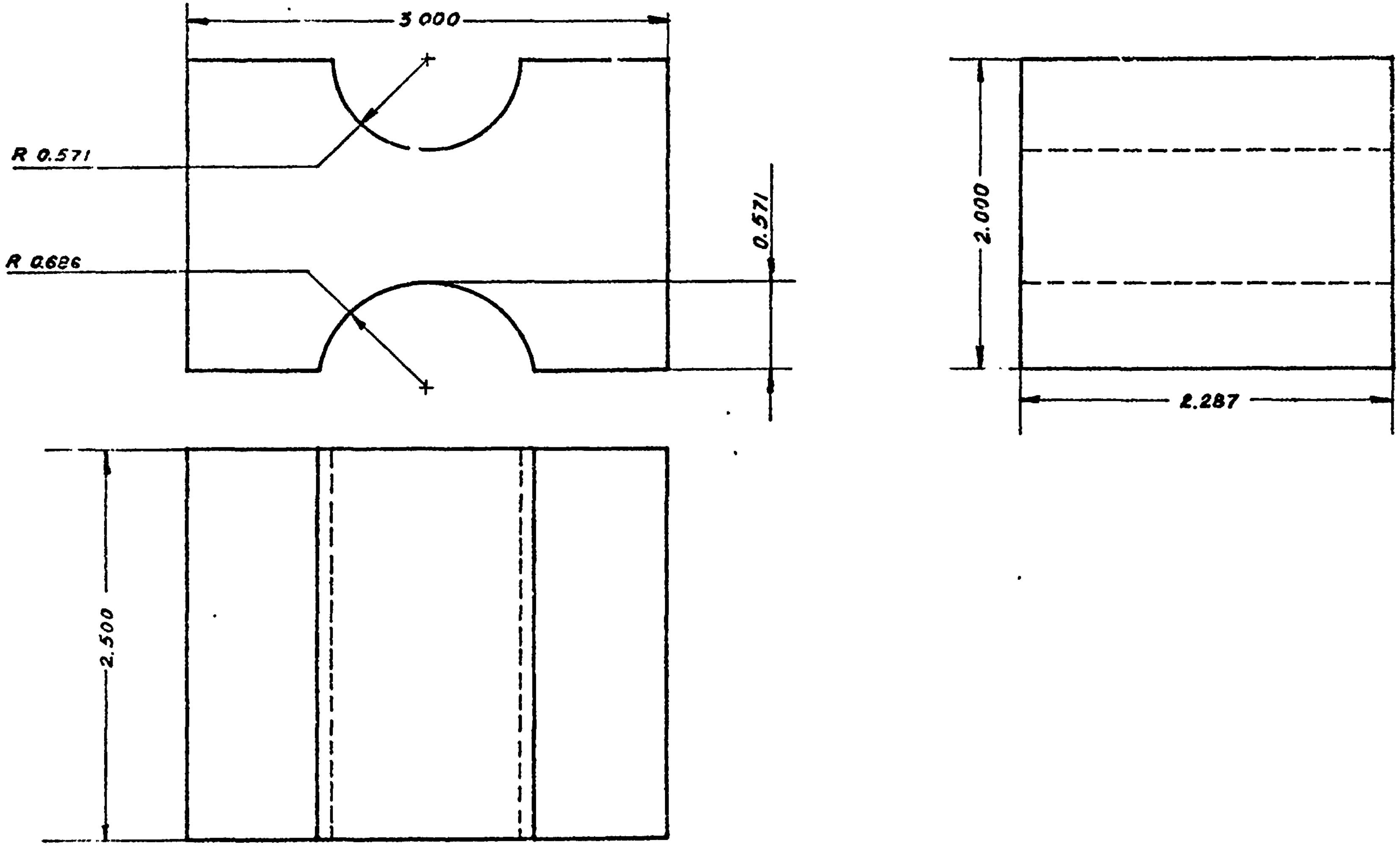
Contract No. N00024-70-C-5439	Name: SPECIMEN ASSEMBLY	Date: May 21, 1971
Matl.	Drawing No. 1	Drawn by: G. Ome
	Scale 1:2	Checked by: F. Matonzo



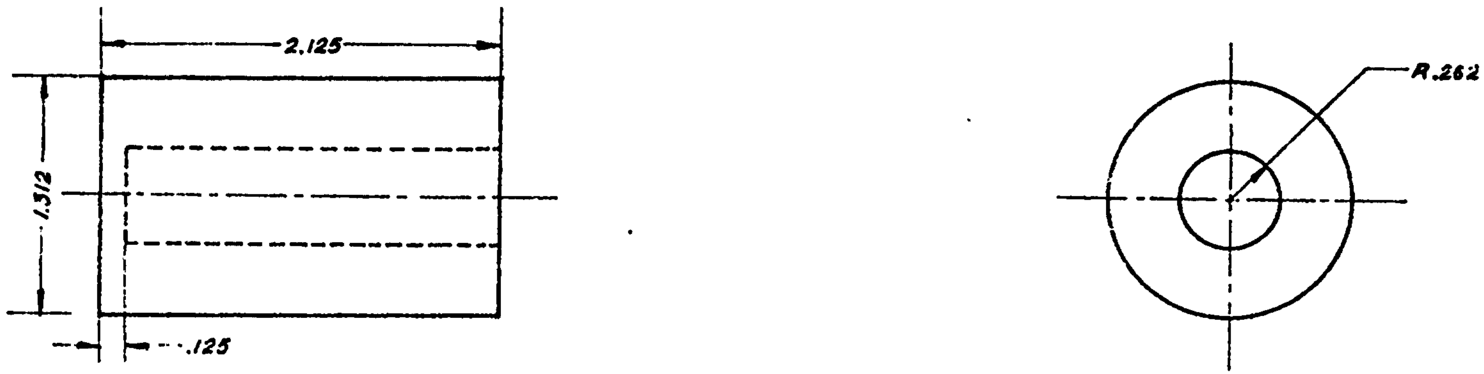
Contract No. N00024-70-C-5439	Name : SPECIMEN DIMENSIONS	Date : May 19, 1971
Matl. : Improved plow steel	Drawing No. 1	Drawn by : G. Ome
	Scale 1:1	Checked by : F. Matanzo



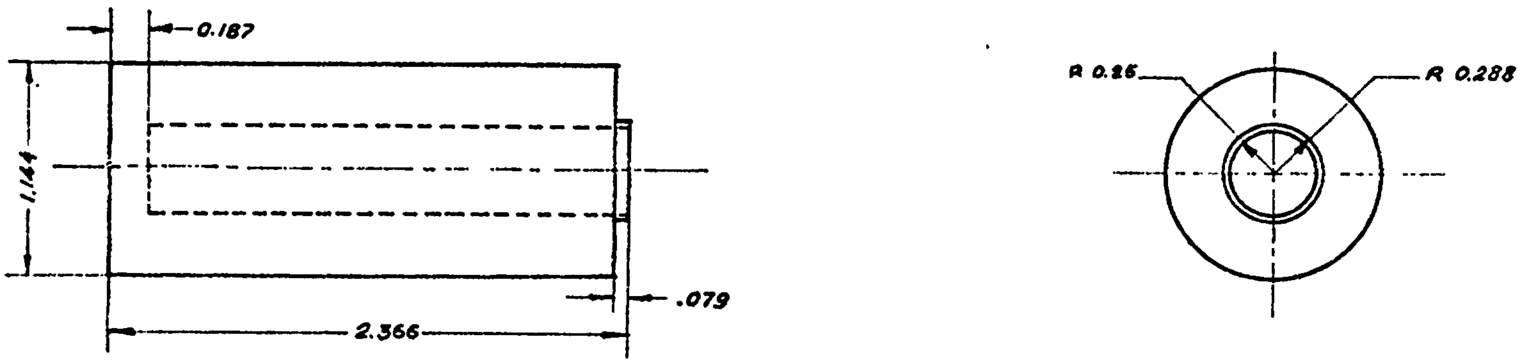
Contract No. N00024-70-C-5439	Name : Adaptor	Date : May 17, 1971
Matl. 1010 Steel	Drawing No. 1	Drawn by : G. Ome
	Scale 1:1	Checked by : R Matanzo



Contract No. N00024-70-C-5439	Name : PRESSING DIE	Date : May 18, 1971
Matl. 4340 Steel	Drawing No. 1	Drawn by : G. Ome
	Scale 1:1	Checked by : F. Molonzo

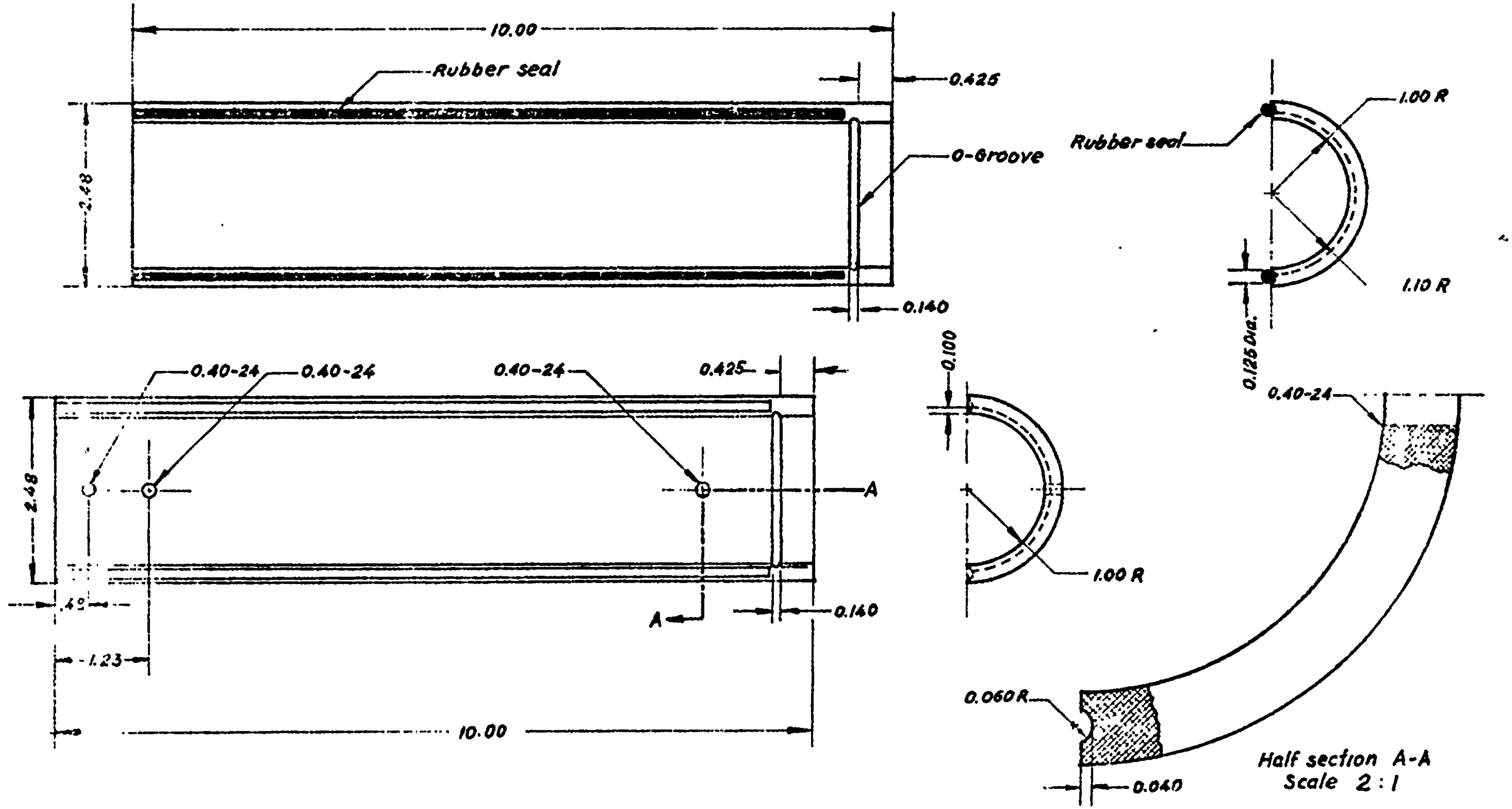


Bushing' before pressing



Bushing after pressing

Contract No. N00024-70-C-5439 Matl 6061-T651 Alum.; Ann. @ 775°F for 2 hrs.	Name : Aluminum bushing Drawing No. 1 Scale : 1:1	Date : May 17, 1971 Drawn by : G. Ome Chocked by : F. Matanzo



Contract No. N00024-70-C-5439	Name COOLANT SLEEVE	Date: May 20, 1971
Matl. Aluminum.	Drawing No. 1	Drawn by: G. Ome
	Scale 1:2	Checked by: F. Matanzo

Appendix D

Citgo Premium Wire Rope Compound

Product Bulletin

PGR 17N

CITGO PREMIUM WIRE ROPE COMPOUND

DESCRIPTION: This product is a light-colored wire rope compound designed to provide superior lubrication of individual wires and strands during fabrication of wire ropes and cables at the mill.

QUALITIES: CITGO Premium Wire Rope Compound has the following physical and performance characteristics which make it an outstanding product:

Special additives used in its formulation provide improved antiwear and extreme pressure properties as compared to conventional asphaltic base wire rope lubricants.

It provides excellent rust protection not only under normal condensate type moisture conditions such as prolonged storage, but also where salt water corrosion may be a problem.

This product may be applied to damp metal surfaces. When applied, CITGO Premium Wire Rope Compound penetrates and displaces the surface moisture providing a water free protective coating and lubricant.

CITGO Premium Wire Rope Compound, because of its lighter viscosity, can be applied at a lower temperature than can asphaltic base products.

The melting point of the new CITGO Premium Wire Rope Compound is sufficiently high to prevent it from dripping from the rope in warm weather operations, or in hot storage buildings.

The light amber color of CITGO Premium Wire Rope Compound affords the coated rope a more pleasing appearance than does the black color of the conventional asphaltic lubricant. This feature not only promotes excellent sales appeal, but permits easy inspection of the outer strands of wire during service.

CITGO Premium Wire Rope Compound surpasses asphaltic products on the Sheave Drip Test, which is a means of evaluating the performance of a wire rope lubricant used on rotary drill cables, where the lubricant

July 15, 1970

could be thrown off due to centrifugal force. This condition occurs particularly where the rope is operating in hot climates.

It will not flake or chip off the wire during cold weather service in the field. This condition could expose the steel wires to the atmosphere resulting in possible corrosion.

APPLICATION: CITGO Premium Wire Rope Compound is recommended for internal lubrication and as a protective coating for all types of wire ropes and cables during the process of manufacture.

SPECIFICATIONS:

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	CITGO PREMIUM WIRE ROPE COMPOUND
Color	Dark Brown
Penetration, ASTM D937	75-110
Melting Point, °F Min., ASTM D127	180
4 Ball E. P. Weld Value, Kgs., Min.	190
Mean Hertz Load (1)	40
4 Ball Wear Test (1) (3)	0.34
Humidity Test (1) (6)	Pass
Salt Water Immersion Test, 10% Salt, 30 Days (1)	Pass
Timken O. K. Load (1) (2)	20
Flash Point, °F Min.	460
Fire Point, °F Min.	550
Viscosity, SUS @ 210°F	235-265
Specific Gravity @ 60°F (1)	0.9232
Neutralization No. (1)	1.8
Ring and Ball Softening Point, °F, ASTM D28 (1)	150
Corrosion, ASTM, Max. (4)	1
Volatile Matter, Loss Wt. % (1) (5)	0.16
Oxygen Bomb 200 hours, Lbs. Drop (1)	10
Flaking and Cracking Resistance, °F, Pass (1) (7)	-20
Brittle Point, °F (1) (8)	
1/32" Film, 1 Hr. does not crack at	-60
3/32" Film, 1 Hr. does not crack at	-30

NOTES: (1) Approximate - for information only.
(2) Modified U. S. Steel Method; 4 grams, 10 minutes.
(3) 1 hour at 130°F, 20 Kg. load, 1800 RPM; Scar Diameter mm.
(4) ASTM D130 - 3 hours at 212°F.
(5) 3 hours at 225°F, Method MIL-G-18453A.
(6) 42 days at 120°F, 100% relative humidity.
(7) Coated 5/8" 6 x 19 wire core rope.
(8) 1/4" mandrel and 180° bend 0.5" x 6" x .01" steel strips.

APPENDIX E

COMPOSITION OF IMPROVED PLOW STEEL

LADLE ANALYSIS OF HEAT #412B4342

OF IMPROVED PLOW STEEL

Element	Per Cent
Carbon	0.640
Manganese	0.550
Phosphorus	0.011
Sulfur	0.016
Silicon	0.210